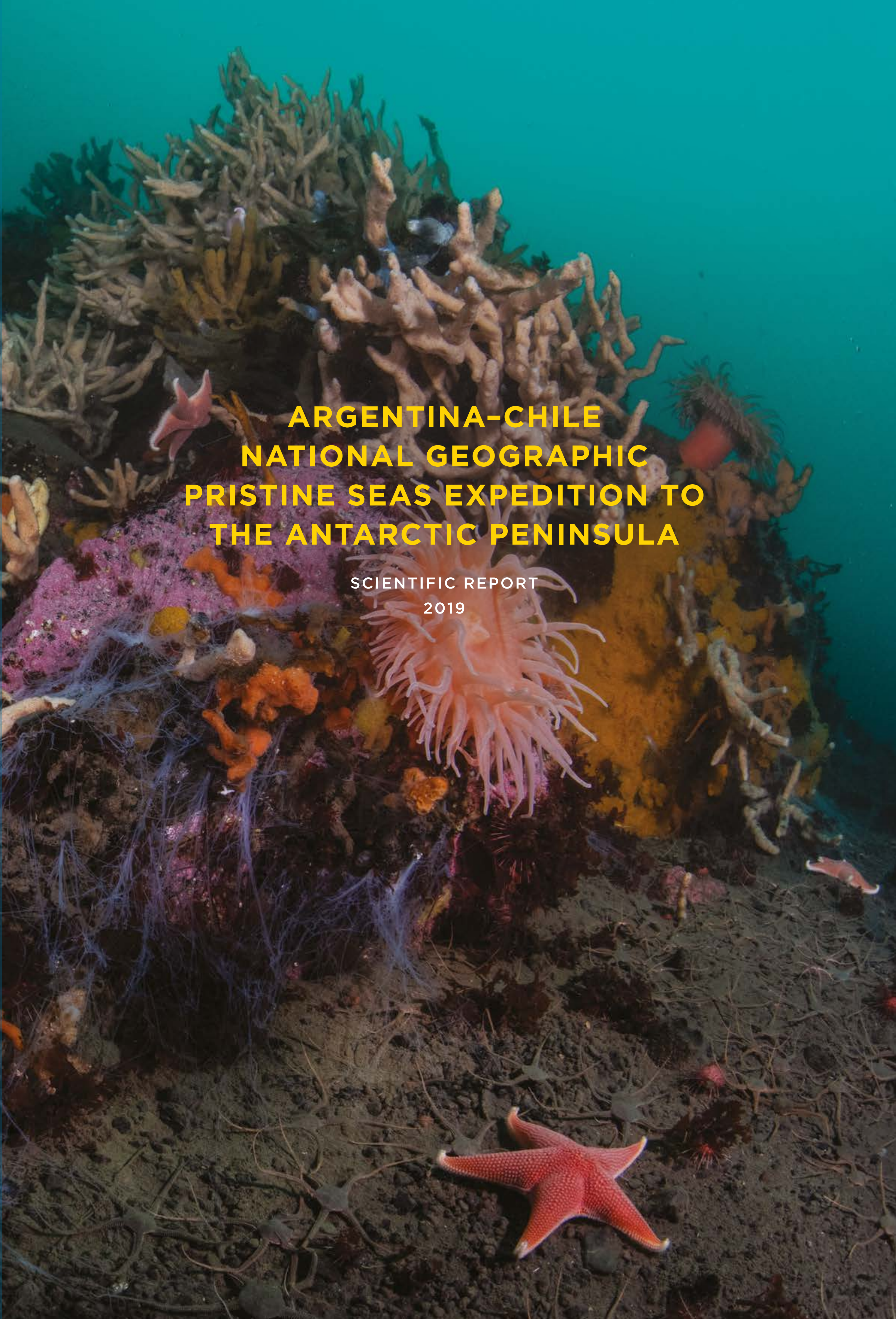
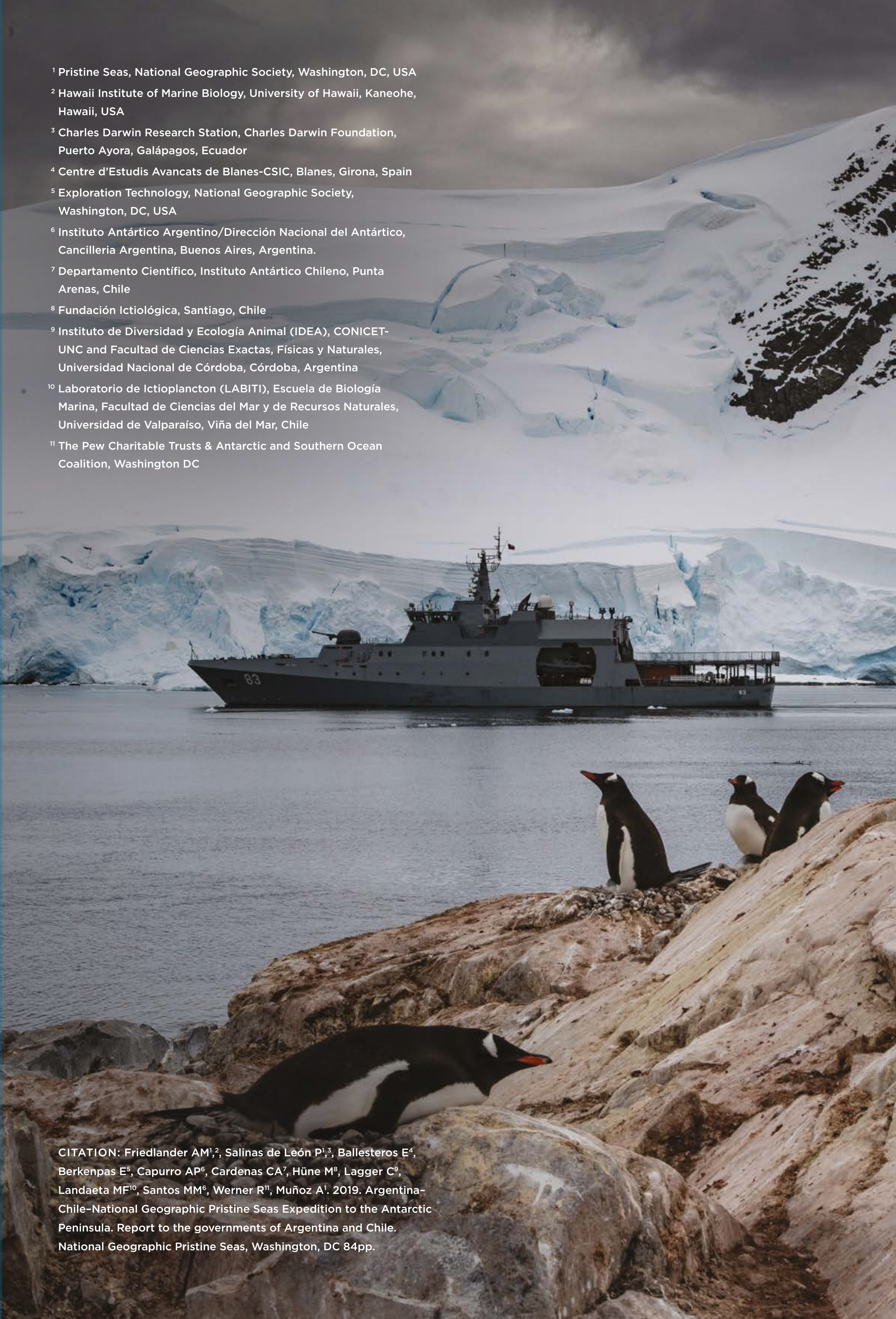


ARGENTINA-CHILE NATIONAL GEOGRAPHIC PRISTINE SEAS EXPEDITION TO THE ANTARCTIC PENINSULA

SCIENTIFIC REPORT

2019



[1] Pristine Seas, National Geographic Society, Washington, DC, USA

[2] Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, Hawaii, USA

[3] Charles Darwin Research Station, Charles Darwin Foundation, Puerto Ayora, Galápagos, Ecuador

[4] Centre d'Estudis Avancats de Blanes-CSIC, Blanes, Girona, Spain

[5] Exploration Technology, National Geographic Society, Washington, DC, USA

[6] Instituto Antártico Argentino/Dirección Nacional del Antártico, Cancilleria Argentina, Buenos Aires, Argentina.

[7] Departamento Científico, Instituto Antártico Chileno, Punta Arenas, Chile

[8] Fundación Ictiológica, Santiago, Chile

[9] Instituto de Diversidad y Ecología Animal (IDEA), CONICET-UNC and Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Córdoba, Argentina

[10] Laboratorio de Ictioplancton (LABITI), Escuela de Biología Marina, Facultad de Ciencias del Mar y de Recursos Naturales, Universidad de Valparaíso, Viña del Mar, Chile

[11] The Pew Charitable Trusts & Antarctic and Southern Ocean Coalition, Washington DC

CITATION: Friedlander AM[1,2], Salinas de León P[1,3], Ballesteros E[4], Berkenpas E[5], Capurro AP[6], Cardenas CA[7], Hüne M[8], Lagger C[9], Landaeta MF[10], Santos MM[6], Werner R[11], Muñoz A[1]. 2019. Argentina–Chile–National Geographic Pristine Seas Expedition to the Antarctic Peninsula. Report to the governments of Argentina and Chile. National Geographic Pristine Seas, Washington, DC 84pp.

TABLE OF **CONTENTS**

EXECUTIVE SUMMARY

EXECUTIVE **SUMMARY**

The Southern Ocean, surrounding Antarctica, is one of the least altered marine ecosystems on Earth. The Antarctic Circumpolar Current acts as a strong biogeographic barrier, resulting in a large proportion of endemic species in Antarctic waters. The great abundance of plankton around the Antarctic Peninsula supports one of the most important areas for krill in the Southern Ocean, which in turn supports large breeding populations of fishes, penguins, seabirds, seals and whales resulting in one of the largest foodwebs on the planet. Together with its unique biodiversity, and due to intense summer productivity, the region is responsible for ~20% of global atmospheric CO_2 draw-down.

Despite its global importance, large areas of the marine realm of Antarctica have never been sampled and much of the biology is poorly known, especially in areas away from the proximity of international research stations. Along the Antarctic Peninsula-Scotia Sea area, the ecosystem is changing rapidly due to the impact of climate change and increased temperatures that are warming faster than nearly anywhere else on Earth, threatening a rich but delicate biological community.

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was established by international convention in 1982 with the objective of conserving Antarctic marine life. Recognizing the value of marine protected areas (MPAs) in supporting ecosystem health, CCAMLR became the first international body to commit to creating an MPA network. CCAMLR's commitment was based on a mission to protect, rather than exploit, life in the Southern Ocean, as well as to implement the precautionary principle, which errs on the side of conservation when the best available science is limited or unclear.

In January 2019, the governments of Chile and Argentina, in collaboration with National Geographic Pristine Seas, organized an expedition to the Antarctic Peninsula, with the aim to provide political, scientific, and communication support, at a global scale, to the Marine Protected Area proposal for the Antarctic Peninsula-South Scotia Arc (Domain 1 MPA or D1MPA) that was put forward jointly by the two countries in October 2018. This bi-national expedition was conducted on the Chilean Navy vessel, the OPV-83 Marinero Fuentealba, with scientists from both countries national Antarctic Institutes. This expedition surveyed the western part of the Antarctic Peninsula, characterizing the underwater biological communities using a combination of visual and photographic surveys using SCUBA, and deep-sea cameras.

BENTHIC COMMUNITIES

Our results add to the rich body of scientific information from Antarctica, providing data from locations away from the proximity of international research stations, which helps to characterize these unique communities across a range of depths and habitats. Nearshore communities were strongly influenced by the effect of ice, while in shallow waters from 5 to 25 m depth distinct and heterogeneous communities of macroalgae (primarily dominated by *Himantothallus grandifolius* and *Desmarestia* spp.) proliferate. The understory of these assemblages was extremely rich in macroalgae, as well as sessile and vagile macroinvertebrates. Cryptic habitats such as vertical walls and overhangs often provided shelter from disturbance produced by icebergs, hosting highly diverse and well-developed communities at shallow depths that included bryozoans and encrusting sponges. At some of the stations on steep walls, carpets of benthic filamentous diatoms (mainly *Paralia* sp.) were abundant.

At depths greater than 25 m, sponges, erect bryozoans, ascidians, gorgonians, and other filter-feeding organisms dominated. These deeper areas are protected from ice scour and form persistent communities that constitute complex three-dimensional components, which play a key role in the Antarctic ecosystem by providing refuge and food for a wide range of organisms.

FISHES

Fish species endemic to the Scotia Arc and the Antarctic Peninsula accounted for 50% of the nearshore species observed. Nototheniidae was the most species rich family, accounting for 71.4% of all species observed. The dusky notothen (*Trematomus newnesi*) was the most frequently encountered fish species (50% of the stations), followed by the gaudy notothen (*Lepidonotothen nudifrons*, 36%) and the bullhead notothen (*N. coriiceps*, 36%). Despite low species richness, the region is a present-day hotspot of fish species formation and is dominated by the radiation of highly specialized and geographically restricted species (e.g. Nototheniidae), which have the fastest rates of speciation of marine fishes of any region on Earth.

DEEP-SEA

We deployed baited Deep-ocean Dropcams at 24 locations ranging in depth from 90 to 797 m to explore these deeper areas. Crocodile icefishes (Channichthyidae) was the most commonly occurring fish family, observed on nearly 90% of the deployments, followed by Barracudinas (Paralepididae; 68% of deployments). Cod icefishes (Nototheniidae) and Lanternfishes (Myctophidae) occurred on 47% and 42% of the deployments, respectively. Lanternfishes were observed only at depths greater than 374 m but was the most abundant family observed. Krill were the most prevalent and abundant taxa of invertebrates, observed on every deployment, at times with over 100 individuals per frame. We also identified a number of taxa that are classified as Vulnerable Marine Ecosystem (VME) taxa, including cold water corals and sponge fields.

SEABIRDS

With over 45 bird species recorded in Antarctica, the Antarctic Peninsula represents an important foraging and breeding area for many species. The great abundance of krill in its adjacent waters represents one of the largest concentrations of this crustacean across the continent, providing vital foraging opportunities to a wide range of seabird species. In addition, ice-free land areas on the Antarctic Peninsula and adjacent islands, represent essential breeding grounds.

Adélie penguins are decreasing at almost all locations on the Antarctic Peninsula, while chinstrap penguins are also declining regionally, with population declines in excess of 50% throughout their breeding range. The observed declines have been linked to climate change and the increased competition for krill from baleen whales and pinnipeds as their populations recover from human harvesting, as well as increasing krill fishing.

MARINE MAMMALS

There are 21 marine mammal species recorded in the Antarctic, including 6 species of pinnipeds and 15 species of cetaceans. Of the 6 pinniped species, 4 are endemic to the Southern Ocean, with crabeater seals by far the most abundant. Krill is the major item in the diet of crabeater seals and makes up around half the food eaten by leopard seals. A large influx of male Antarctic fur seals from Subarea 48.3 into Domain 1 occurs in late summer/early autumn, and accounting for this large, transient population of krill-dependent predators was an important consideration for the MPA planning process. All seven species of baleen whales that occur south of the Antarctic Polar Front have been extensively exploited. Humpback whales (*Megaptera novaeangliae*) have recovered to become the most numerous whale species in the region. However, three whale species—blue (*Balaenoptera musculus*), fin (*B. physalus*) and sei (*B. borealis*)—are listed as Endangered by IUCN. The use of Antarctic waters during the brief summer feeding season, highlights the importance of these waters for this highly threatened group of species.

FISHERIES

Historically, krill fishing has been the largest fishery in the Southern Ocean and CCAMLR has successfully managed this fishery using a precautionary approach, while also allowing the recovery of certain fish species that were overexploited in the past. However, the fishery has concentrated its efforts in certain areas in more recent years (e.g., Bransfield Strait [Mar de la Flota*]). Changes in the dynamics of the krill fishery (e.g., technology, economics, species distribution patterns), along with current and projected changes in the marine environment around the Antarctic Peninsula, are challenging the way the krill fishery is managed.

Patagonian toothfish (*Dissostichus eleginoides*) and Antarctic toothfish (*D. mawsoni*) are targeted by authorized fisheries in the Southern Ocean, using mainly bottom-set longlines in depths of 1,200–1,800 m. These highly prized fishes have also caught the attention of illegal, unreported, and unregulated fishing vessels in the Southern Ocean. Commercial fishing for toothfish species is currently not happening in the Antarctic Peninsula area. On the contrary, mackerel icefish (*Champsocephalus gunnari*) was heavily exploited in the 1970s and 1980s in this area and concerns over the levels of exploitation, and the high annual variability in catches, led to the closure of the fisheries in the early 1990s.

CLIMATE CHANGE

The Western Antarctic Peninsula has warmed significantly over recent decades and is considered among the fastest warming regions on Earth. Climate change is a major threat to the long-term survival of Antarctic marine communities. The rapid warming of high-latitude ecosystems can also have major implications for fisheries, including the distribution of krill populations in the Southern Ocean. This changing distribution is already altering Antarctic food webs that rely heavily on krill and could have an impact on biogeochemical cycling.

TOURISM

Tourism to Antarctic coastal areas began in the late 1950s and early 1960s with one or two chartered ships carrying a few hundred passengers along with a handful of yachtsmen. During the 2018–19 Antarctic season, the total number of visitors traveling with the International Association of Antarctica Tour Operators was 56,168, representing an increase of 8.6% compared to the previous season, with most visits occurring in the west peninsula area. The Antarctic Treaty System is looking at the possible impacts of these visits and at the growth and certain tendencies in development of Antarctic tourism.

* According to Argentine nomenclature.

INVASIVE SPECIES

Global warming is now removing the physiological barriers that have isolated Antarctica from lower latitudes. Predictive scenarios suggest that king crabs have the potential to expand their distribution south, which could have dramatic consequences for Antarctic benthic communities. This along with the new evidence of a "permeable" Antarctic Circumpolar Current will transform a previously hostile habitat for many non-Antarctic species into a habitat with more suitable conditions for species that have been absent for millions of years from the fragile Antarctic ecosystem.

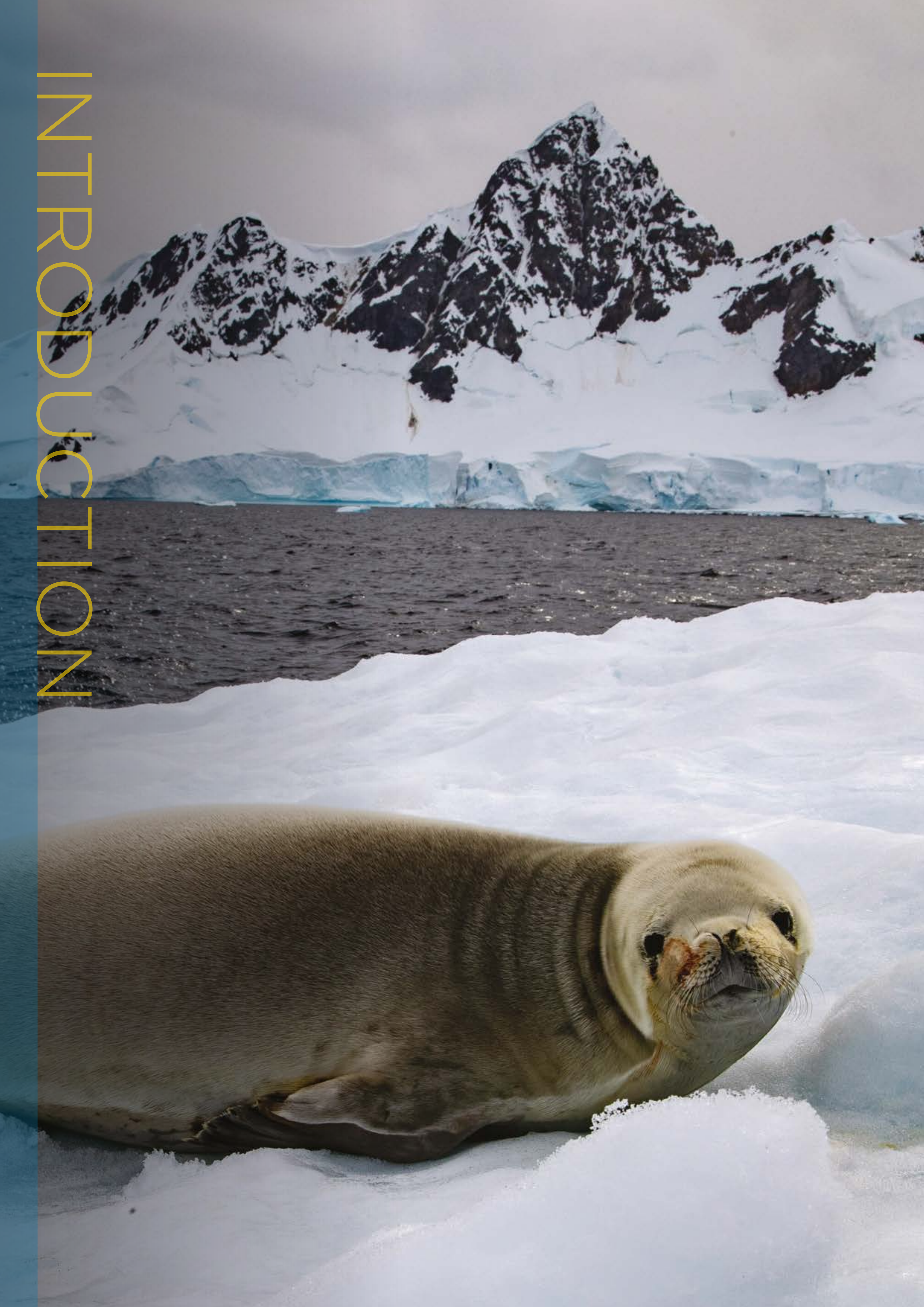
CONSERVATION OPPORTUNITIES

A number of small Antarctic Specially Protected Areas (ASPAs) are already scattered throughout Domain 1, including around the South Shetland Islands and the Palmer Archipelago. ASPAs, managed by the Antarctic Treaty Consultative Meeting, are small protected areas that are generally terrestrial, and only a few include small marine components. Consequently, ASPAs with a marine component are inadequate to protect the Antarctic Peninsula's krill populations, millions of breeding seabirds, marine mammals, and the greater marine ecosystem.

The process to designate a large MPA in the Antarctic Peninsula and South Scotia Arc (referred to by CCAMLR as Domain 1) has been led by Argentina and Chile and started in 2012. Since then, more than 150 spatial layers of scientific data were created in a collaborative process involving many CCAMLR members. These layers describe the spatial distribution of ecosystem processes, habitats and key species, and contain data on human activities such as fishing, tourism, scientific, and logistic activities.

The Domain 1 MPA (or D1MPA) protects biodiversity hotspots as well as representative and unique benthic and pelagic habitats. It includes no-fishing zones in some coastal areas that are important foraging grounds for birds and marine mammals, including penguins and whales, and of relevance for krill and fishes during certain stages of their life cycles, predominantly in the Bransfield (Mar de la Flota*) and Gerlache straits. In these two areas where krill fishing activities have increased in recent years, the fishery directly competes with krill predators such as penguins and whales and may adversely affect these sensitive species. D1MPA also protects sensitive spawning and nursery habitats for krill and for other commercially and ecologically valuable fish species (i.e. icefish, silverfish, and toothfish), as well as key breeding, foraging, and migration areas for seabirds and marine mammals. It also includes zones for scientific studies on climate change, and zones where sustainable krill fishing is allowed, aimed at avoiding the concentration of the fishery in key areas.

INTRODUCTION



INTRODUCTION

The Southern Ocean, surrounding Antarctica, is one of the least altered marine ecosystems on Earth. It encompasses 15% of the world's oceans and is home to hundreds of species found nowhere else. Together with its unique biodiversity, and due to intense summer productivity, the region is responsible for ~20% of global atmospheric CO_2 draw-down (Le Quéré et al. 2007).

Despite its global importance, large areas of Antarctica have never been sampled and much of the biology is poorly known, away from the proximity of international research stations (Barnes & Clarke 2011). The ecosystem is changing rapidly due to the impact of climate change and increased temperatures that are warming faster than anywhere else on Earth, threatening a rich but delicate biological community.

In January 2019, the governments of Chile and Argentina, in collaboration with National Geographic Pristine Seas, organized a bi-national expedition to the Antarctic Peninsula, with the aim to provide political, scientific, and communication support, at a global scale, to the Marine Protected Area proposal for the Antarctic Peninsula (D1MPA) that was put forward jointly by the two countries in October 2018.

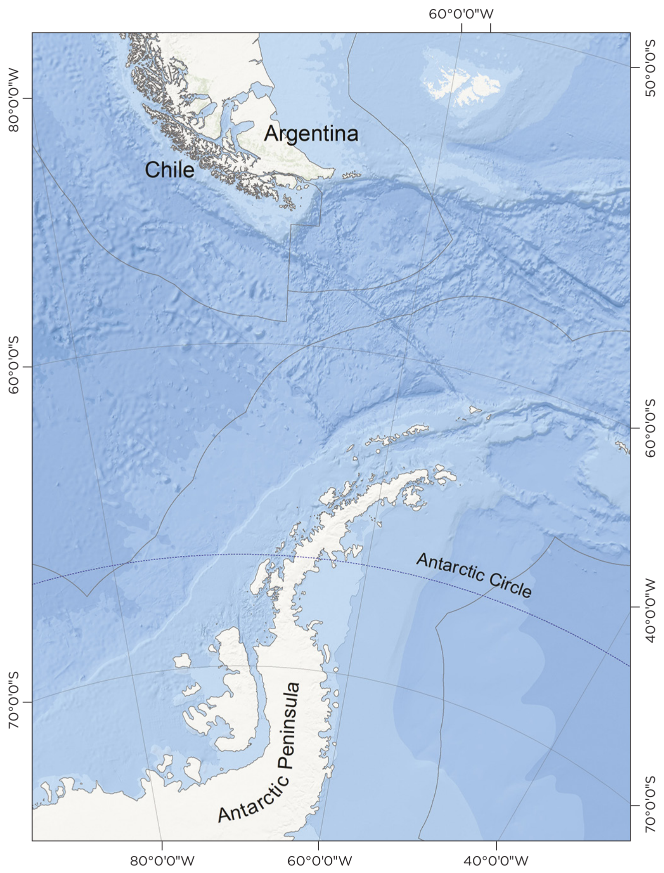
The specific goals of this expedition were to increase scientific knowledge by conducting research with methodologies and equipment not often used in this region; strengthen the relationship and collaboration between Chile and Argentina; and produce and disseminate a full documentary in support of the D1MPA conservation proposal.

1.1. Geology of the Antarctic Peninsula

The Antarctic Peninsula (AP) represents the northernmost portion of the Antarctic continent and is located approximately 1,000 km south from the southern tip of South America, across the Drake Passage. It extends for approximately 1,300 km between the Antarctic mainland and the tip of the Peninsula at the end of Graham Land (Tierra de San Martin*) (Figure 1).

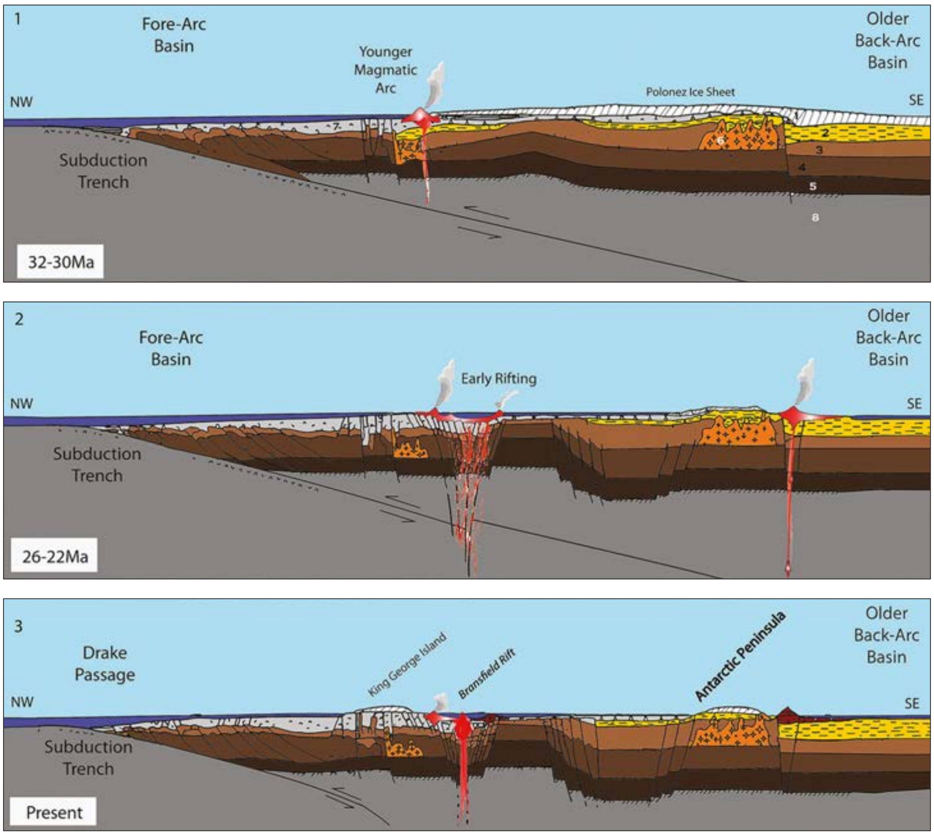
FIGURE 1.

Location of the Antarctic Peninsula in reference to the southern tip of South America.



The AP is an example of ocean-continent plate collision resulting in subduction, a process similar to the associated Andean subduction margin. The modern geology of the Antarctic Peninsula occurred in three main stages since the Permian-Late Triassic Period and has experienced continuous subduction for over 200 million years (Birkenmajer 1994) (Figure 2). The latest stage in the evolution of the Antarctic Peninsula subduction zone was the opening of the Bransfield Rift during the Oligocene, separating the Antarctic Peninsula (older magmatic arc) from the South Shetland Islands (younger magmatic arc) (Galindo-Zaldivar et al. 2004). This resulted in the creation of the Bransfield Strait (Mar de la Flota*) at around four million years ago (Figure 3).

FIGURE 2.



Generalized cross-section of the Antarctic-Phoenix subduction zone. Source: Image modified from Birkenmajer, 1994.

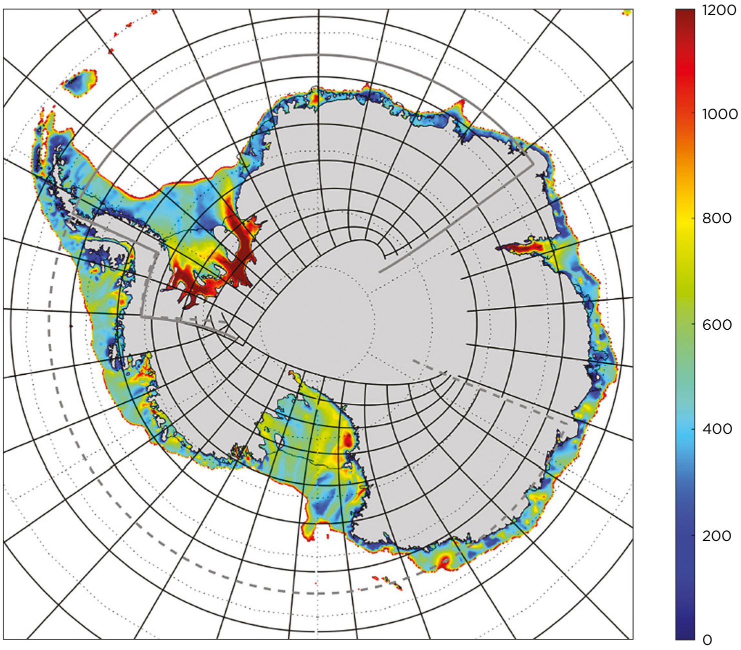
FIGURE 3.

View of the Antarctic Peninsula from the Bransfield Strait (Mar de la Flota*). Jordi Chias/NGS.

The Antarctic continental shelf is unusually deep, with an average depth of 450 m and in places over 1,000 m deep. The average width of the shelf is almost twice that of shelves elsewhere in the world (~ 125 km) and constitutes about 11.4% of the world's continental shelf area (Clarke & Johnston 2003). The shelf sediments are a combination of glacial deposits and diatomaceous muds (Griffiths 2010) (Figure 4).

FIGURE 4.

Bathymetry (m) over the Antarctic continental shelf and beneath the ice shelves. Source: Mathiot et al. 2017.

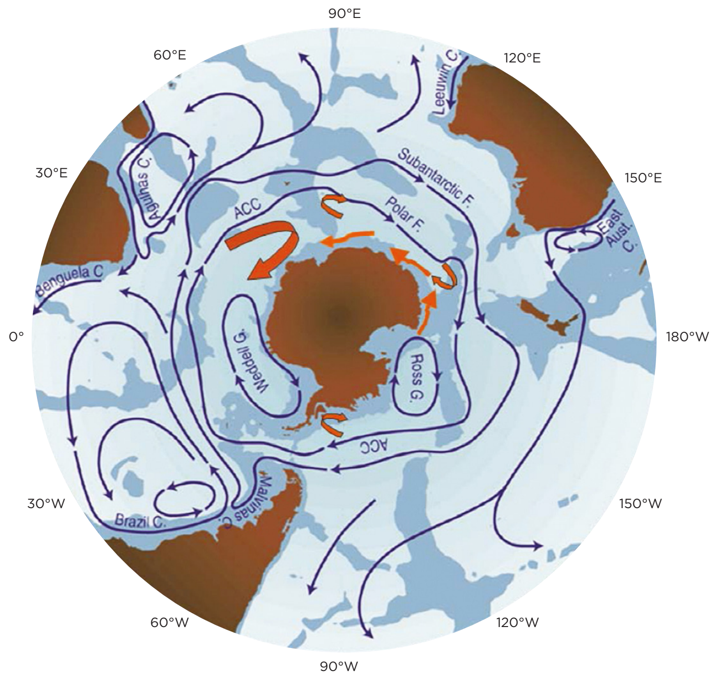


1.2. Oceanography (Antarctic Circumpolar Current)

Forty million years ago, the Peninsula was an isthmus connecting the two continents. Then tectonic activity carried Antarctica farther toward the South Pole, opening the Drake Passage, which is now a thousand kilometres of open water between Cape Horn and the northern extremity of the Peninsula. The opening to deep water flow of the Drake Passage ~29 Ma removed the last land barrier to ocean circulation at 60 degrees south latitude (Lawver & Gahagan 1998). The result was the formation of the Antarctic Circumpolar Current (ACC), which flows from west to east, or clockwise as seen from the South Pole. The development of this circumferential current had a profound effect on the Antarctic climate and biota (Barker & Thomas 2004) (Figure 5).

FIGURE 5.

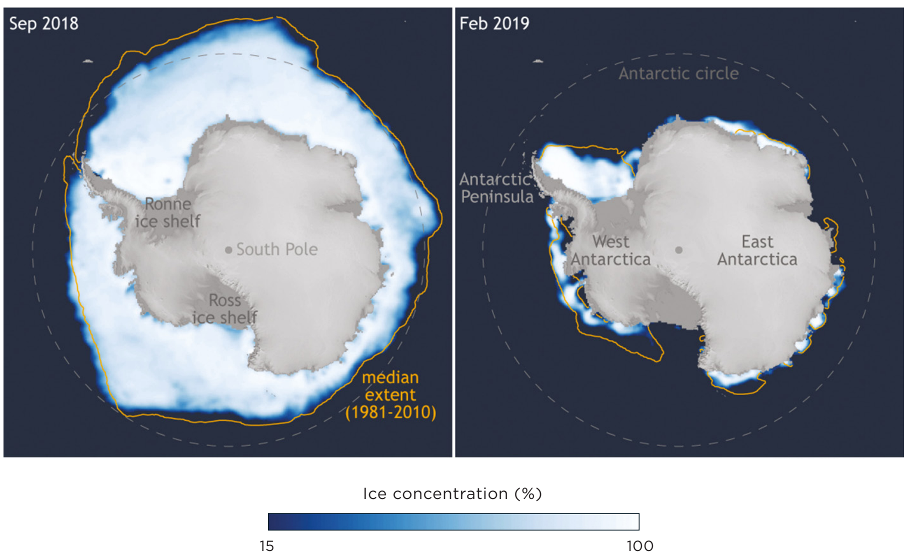
Main currents around Antarctica. Source: United Nations.



The temperature of the ACC water is ~ +2 C°, with little seasonal variation. The area covered by sea ice increases from around 3–4 x 10^6 km^2 in the summer to 18– 20x106 km^2 in winter, essentially doubling the continental surface area of Antarctica each winter (Griffiths 2010) (Figure 6).

FIGURE 6.

Differences in Antarctic sea ice concentration between winter maximum (left) and summer minimum (right). Source: NASA Earth Observatory maps by Joshua Stevens, using AMSR2 data supplied by GCOM-W1/JAXA.

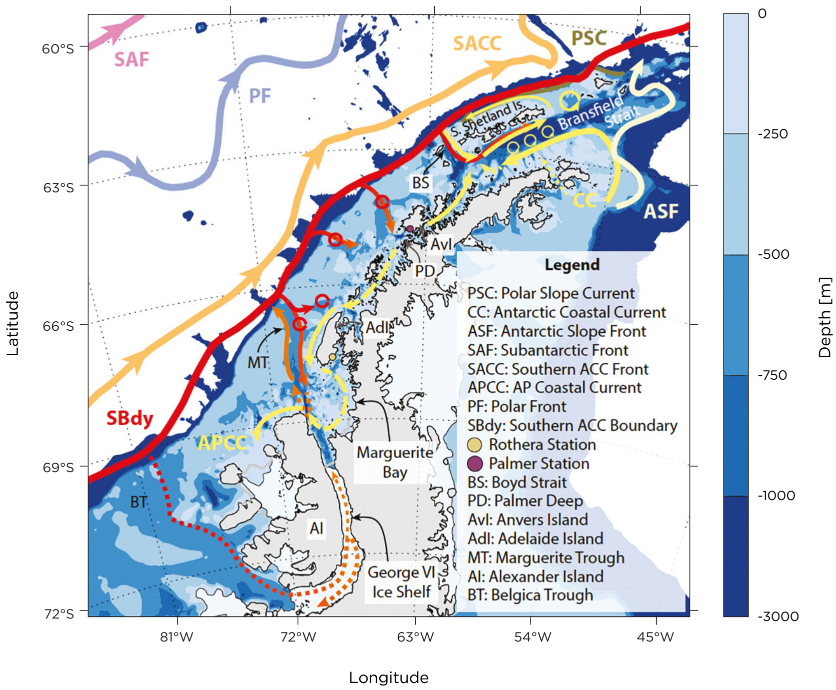


The Southern Ocean has an essential role in the global ocean circulation system and plays a vital role in interacting with the deep-water circulation in each of the Pacific, Atlantic, and Indian oceans. The sea ice formation creates cold, dense, salty water that sinks to the seafloor and forms very dense Antarctic bottom water. This in turn pushes the global ocean's nutrient-rich, deep water closer to the surface, helping to create areas of high primary productivity in Antarctic waters, similar to areas of upwelling elsewhere in the world (Griffiths, 2010).

The circulation around the Antarctic Peninsula has been widely studied on the Bransfield Strait (Mar de la Flota*). The interaction between the coast and/or bathymetry with the currents generates a complex circulation pattern and promotes the generation of meso- and submeso-scales eddies. These structures are favourable for larval retention and advection around the Antarctic Peninsula (Thatje 2005; Moffat & Meredith 2018) (Figure 7).

FIGURE 7.

Overview of the circulation on the West Antarctic Peninsula shelf. Source: Moffat & Meredith 2018.

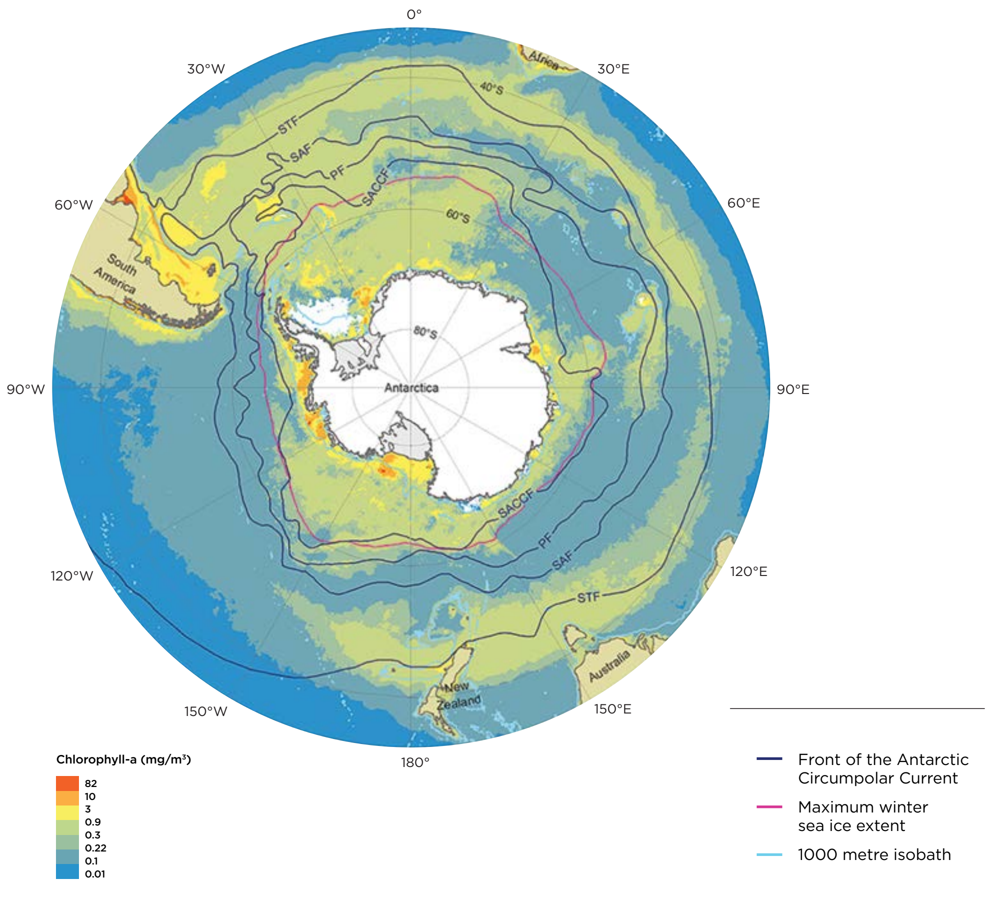


1.3. Marine Ecology

The great ocean productivity around the Antarctic continent, derived from its unique oceanography, sustains one of the largest food webs on the planet. The entire Southern Ocean ecosystem ultimately depends on phytoplankton production for their food. In the nutrient rich coastal waters of Antarctica, phytoplankton blooms reach their maximum concentration during the summer months, especially off the West Antarctic Peninsula, where the highest cell and Chlorophyll-a concentrations are frequently recorded (Deppeler & Davidson 2017). The Antarctic Circumpolar Current also acts as a strong biogeographic barrier, resulting in a large proportion of endemic species in Antarctic waters. The isolation and the particular characteristic of this cold and very stable environment resulted in an ecosystem with a distinctive fauna with many unique characteristics and adaptations to these conditions (De Broyer et al. 2014).

FIGURE 8.

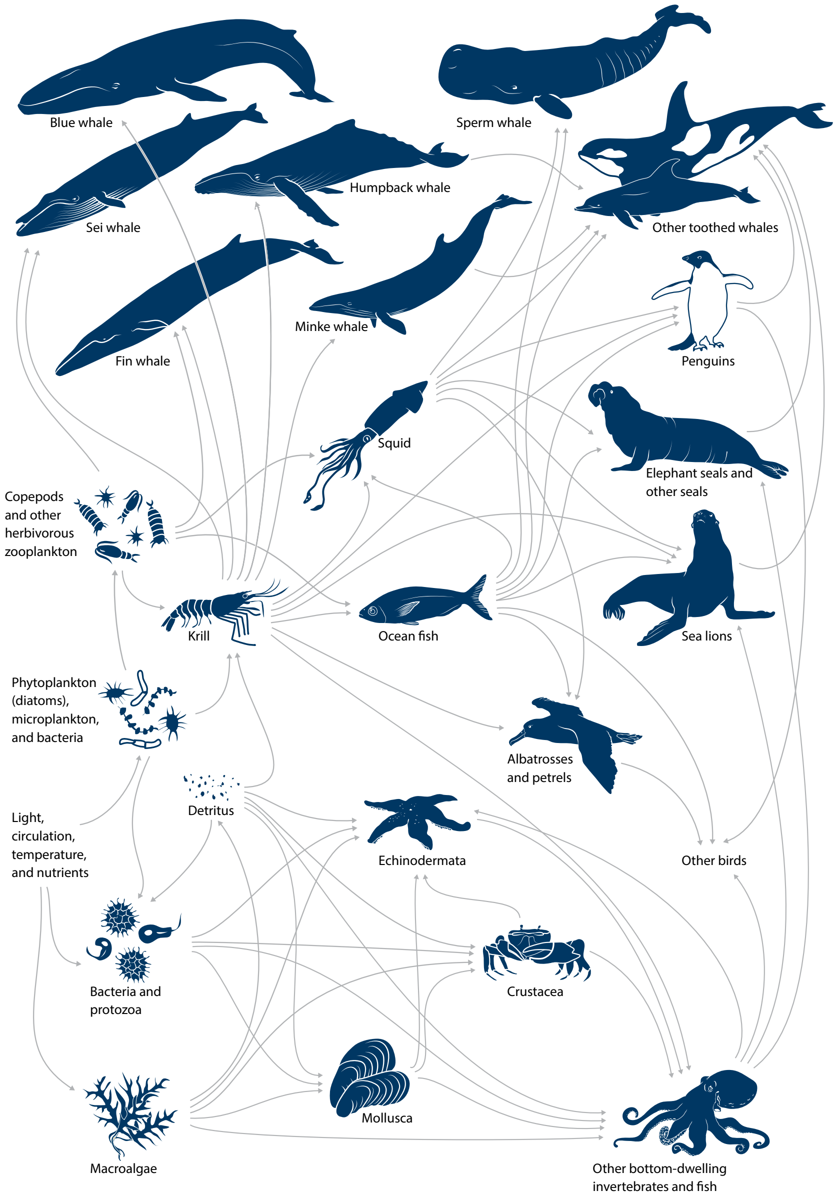
Summer near-surface Chlorophyll-a concentration, front locations and sea ice extent in the Southern Ocean. Source: Deppeler & Davidson 2017.



In the pelagic realm, the great abundance of plankton around the Peninsula supports one of the most important areas for krill in the Southern Ocean (Griffiths, 2010). Three euphausiids, *Euphausia superba* (Antarctic krill), *Thysanoessa macrura* and *Euphausia crystallorophias* (ice krill); a shelled pteropod (*Limacina helicina*); and a salp (*Salpa thompsoni*) are dominant, the latter with a recent expansion in its southmost distribution (Atkinson et al. 2008). However, Antarctic copepods (mostly Calanidae and Oithonidae) also are important biomass in the Antarctic Peninsula (Hopkins 1985, Ashjian et al. 2004) and support trophic interactions with fish larvae (Landaeta et al. 2012, Lagos & Manríquez 2014). This large concentration of krill supports large breeding populations of fishes, penguins, seabirds, seals, and whales resulting in one of the largest foodwebs on the planet (Ducklow 2008) (Figure 9).

FIGURE 9.

Schematic representation of the great Southern Ocean food web. Source: National Geographic Society.



The marine benthos is the richest element of the Antarctic food web in terms of numbers of macro-species, but their roles and interactions are poorly understood and thought to be dominated by suspension feeders in the shallows, and deposit feeders in deeper waters (Griffiths, 2010). It is known that communities dominated by suspension-feeding form complex three-dimensional structures that play a key role in the Antarctic ecosystem by providing refuge and food for a wide range of microorganisms (Gutt et al. 2015). Recent evidence has also shown the importance of benthic communities in carbon turnover (Rovelli et al. 2019). However, our knowledge about other functional roles is still limited. The taxa that have higher species richness include bryozoans, sponges, and amphipods (Arntz et al. 1997). Other marine taxa are as rich or richer than at low latitudes (e.g. holothurians and ascidians) (Griffiths et al., 2010).

Along the Western AP, ice scour is the main physical driver structuring the benthic communities in shallow waters (Gutt & Starmans 2002, Smale et al. 2008). Recent evidence suggests that almost 30% of the seabed is impacted by icebergs in shallow water (< 25 m depth), thus creating a unique community where persistent change occurs, which is characterized by a mosaic of different stages of recolonization and succession (Lagger et al. 2018). The effect of ice creates very distinct and heterogeneous communities around Antarctic waters where macroalgae benthic communities (primarily *Himantothallus grandifolius* and *Desmarestia* spp.) dominate the substrate from 5 to 25 m depth, with sponges and other filter-feeding organisms dominating > 25 m (Barnes & Clarke 1995, Klöser et al. 1996). Canopy-forming algae are architectural species that harbour a diverse assemblage of species, which have been poorly studied in southern high-latitude rocky reefs (Cárdenas et al. 2016) (Figure 10). However, cryptic habitats such as vertical walls and overhangs often provides shelter from disturbance produce by icebergs, hosting highly diverse and well-developed communities at shallow depths (Cárdenas & Montiel 2017).
The Antarctic fish assemblage is dominated by notothenioid species, and some mesopelagic taxa (Myctophidae, Notosudidae, and Bathylagidae). The Antarctic ichthyofauna is limited and less diverse than might be expected, given the size and age of the Antarctic marine ecosystem (Eastman & Grande 1989). In the Southern Ocean, pelagic fishes are rare. Myctophidae (Lantern fish) dominate in terms of species and biomass in oceanic waters; however, they are minor components of the Antarctic epiplankton (Barrera-Oro 2002). Remarkably, the Antarctic fish fauna is unique in being dominated in terms of diversity (35%) and biomass by an endemic coastal demersal group, the suborder Notothenioidei, which includes six families and can be found as deep as 1200–1500 m (Eastman 2013). There is a lower diversity of Antarctic fish species on the continental shelves (139 spp.) compared with other cold-water seas (> 350 spp. in the North Atlantic). However, although the diversity of the notothenioids is limited compared with the large size of the ecosystem, there is no other fish group in the world with such a diversification and dominance in a continental shelf habitat (Barrera-Oro 2002, Eastman 2013).

FIGURE 10.

Example of a diverse shallow water benthic habitat on the Western Antarctic Peninsula. Manu San Félix/NGS.

1.4. Antarctic Governance

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was established by international convention in 1982 with the objective of conserving Antarctic marine life. This was established in response to increasing commercial interest in Antarctic krill resources, a keystone component of the Antarctic ecosystem and a history of over-exploitation of several other marine resources in the Southern Ocean (Figure 11).

CCAMLR is an international commission made up of 24 countries and the European Union. It was a pioneer in formulating ecosystem and precautionary approaches as basic principles for the management of marine living resources. The CCAMLR Convention applies to all Antarctic populations of finfish, mollusks, crustaceans, and seabirds found south of the Antarctic Convergence. While prioritizing conservation, CCAMLR allows limited fishing in some areas in accordance with its ecosystem-based management approach.

Based on the best available scientific information, the Commission agrees to a set of conservation measures that determines the use of marine living resources in the Antarctic. The marine resources managed by CCAMLR specifically exclude whales and seals, which are the subject of other conventions – namely, the International Convention for the Regulation of Whaling and the Convention for the Conservation of Antarctic Seals.

CCAMLR's management decisions take the form of Conservation Measures (CMs), which are adopted by consensus at CCAMLR annual meetings, and are binding upon all Members. The Commission work is assisted by its Scientific Committee, which provides a forum for consultation and co-operation concerning the collection, study, and exchange of information with respect to marine living resources. The role of the Scientific Committee in the development of management decisions has been key in the CCAMLR efforts to bring the ecosystem approach into practice. The Scientific Committee has established working groups on different issues of interest to CCAMLR, which help formulate scientific advice to implement the conservation principles of the Convention.

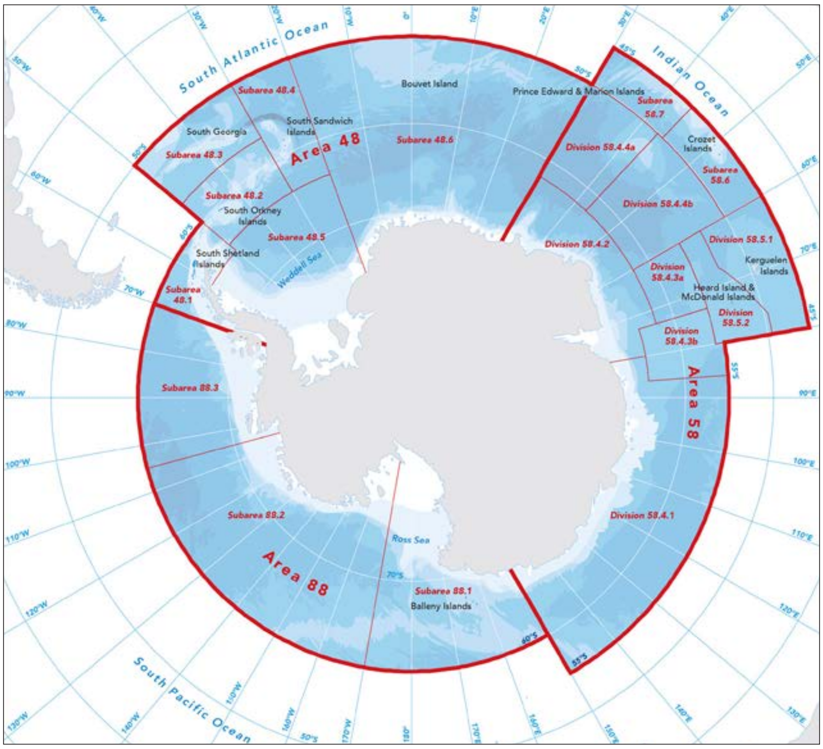


FIGURE 11.

CCAMLR Area including FAO Statistical Areas, Subareas and Divisions. Source: CCAMLR (www.ccamlr.org/en/system/files/CCAMLR-Convention-Area-Map.pdf).

Recognizing the value of marine protected areas (MPAs) in supporting ecosystem health, CCAMLR became the first international body to commit to creating an MPA network. CCAMLR's commitment was based on a mission to protect, rather than exploit, life in the Southern Ocean, as well as to implement the precautionary principle, which errs on the side of conservation when the best available science is limited or unclear. CCAMLR includes MPAs as part of the suite of tools it is using to protect the Southern Ocean.

CCAMLR's commitment to the MPA network has been supported by a series of milestones over the years. In 2005 CCAMLR held its first MPA workshop that was followed by the first bio-regionalization mapping exercise of the Southern Ocean in 2007. In 2009, CCAMLR established the world's first high seas MPA, the South Orkney Islands Southern Shelf MPA, a region covering 94,000 km^2 in the south Atlantic.

By 2011, CCAMLR members agreed by consensus to a framework for creating a network of MPAs by adopting Conservation Measure 91-04 and identifying nine planning domains, which represent areas in which to plan and report on MPAs. With the establishment of the Ross Sea Region MPA in 2016, covering an area of 2.06 million km^2, CCAMLR has taken the first step needed to create a network of MPAs, which would preserve connectivity and provide resilience for the many unique ecosystems of the Southern Ocean.

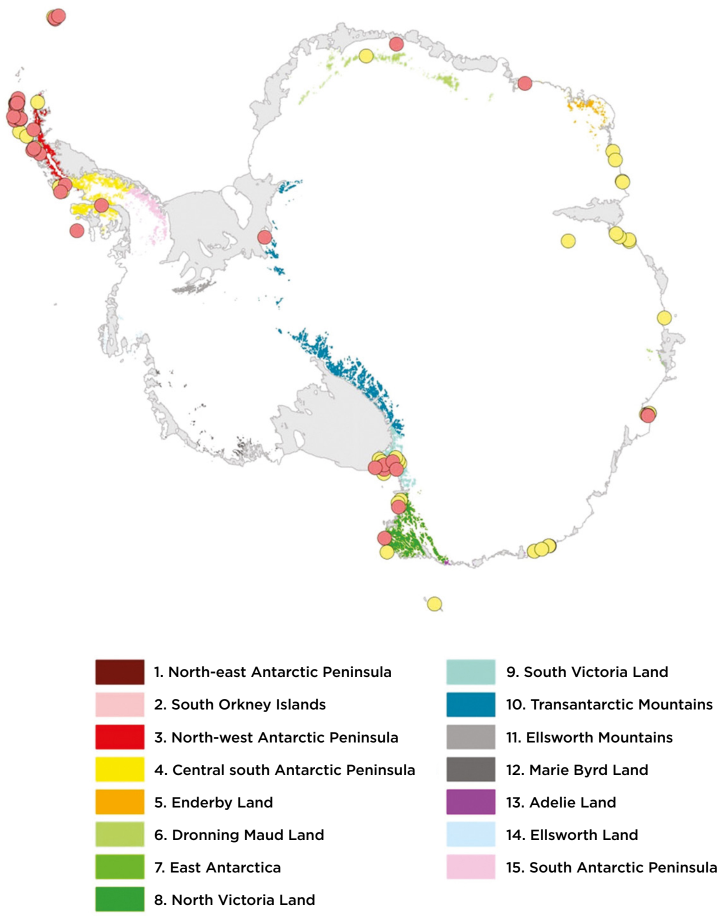
The next steps towards creating this network include designating the proposed Weddell Sea and East Antarctic MPAs, as well as the D1MPA. It is anticipated that CCAMLR members will develop additional MPA proposals to create a truly circumpolar network of protection in the Southern Ocean (Kavanagh et al. 2017).

Besides the work on MPAs conducted by CCAMLR, the Antarctic Treaty Consultative Meeting (ATCM) has been developing its protected area system over the years. Annex V to the Protocol on Environmental Protection to the Antarctic Treaty establishes a framework for designating Antarctic Specially Protected Areas (ASPAs) and Antarctic Specially Managed Areas (ASMAs). These areas are intended to support the objective of protecting comprehensively the Antarctic environment. There are 72 ASPAs and 6 ASMAs currently.

ASPAs are sites with outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research that warrant additional protection due to these values or the risks of human impacts on these values (Figure 12). Important work has been done to underpin the development of a representative series of ASPAs, including spatial analyses to identify distinct 'Environmental Domains' and 'Antarctic Conservation Biogeographic Regions'. The Antarctic Treaty Parties have agreed that these spatial frameworks are useful references to guide the designation of ASPAs within a systematic environmental-geographic framework, and the Antarctic Treaty's Committee for Environmental Protection (CEP) has recognized the need for a more systematic approach to the development of the protected area system.

FIGURE 12.

Network of Antarctic Specially Protected Areas (ASPAs) across the 15 different Antarctic Conservation Biogeographic Regions. Source: Hughes et al. 2016.



In addition, to guarantee the protection of Antarctica, the Antarctic Treaty System and the Protocol for Environmental Protection further includes: 1) the need for every activity planned to occur in the continent to undergo an Environmental Impact Assessment; 2) the prohibition for anyone to enter any ASPA, except with a permit issued by a National Antarctic Program; 3) the prohibition of taking (i.e. removing samples) and of harmful interference (i.e. walking close to colonies, approaching fauna at sea, stepping on native flora), except in accordance with a permit issued by a National Antarctic Program; and 4) the need to be aware of the provisions of the Management Plan that each ASPA and ASMA has, that includes a description of the values, the permitted activities and how to access it. Assuring that the protected areas remain undisturbed and are managed in accordance with their Management Plan is also an important step towards conservation. Nevertheless, the marine component of ASPAs and ASMAs is very small compared to CCAMLR MPAs.

1.5. Current Research by Chile and Argentina

The Instituto Antártico Chileno (Chilean Antarctic Institute/INACH) is a technical organization of the Chilean Ministry of Foreign Affairs, with complete autonomy in scientific, technical, and outreach Antarctic activities. It is the national institution responsible for planning, coordinating, directing and controlling officially authorized scientific and technological activities of the Chilean government and private organizations in Antarctica. INACH organizes and leads its own expeditions and maintains scientific stations in the Antarctic. The Chilean Antarctic Science Program (PROCIEN) brings together universities and centers for scientific research projects that are funded by INACH or other national research financing bodies after going through a peer-review process. Currently, PROCIEN includes about 100 projects in five main areas of research: 1) The state of the Antarctic ecosystem, 2) Antarctic thresholds: ecosystem resilience and adaptation, 3) Antarctic climate change, 4) Astronomy and earth sciences, 5) biotechnology, 6) Human footprint and 7) Social sciences and humanities.

Chilean research in Antarctica nowadays shows particular strengths in the study and understanding of the Antarctic environment, its physical and biological character in both past and present, and in the modeling of future scenarios. The network of research stations located from the South Shetland Islands to Marguerite Bay, provides unique opportunities for monitoring Antarctic ecosystems from a 500 nm transect along the WAP. The final objective of this program is to produce high-quality Chilean Antarctic science of international recognition and in keeping with the Chilean national interests through the delivery of selected studies associated with cultural, economic, and social development.

The Instituto Antártico Argentino (IAA) is a scientific-technological institution dependent from the National Antarctic Directorate (DNA), within the Ministry of Foreign Affairs and Worship, guided under Argentine legislation and policy. It is an active participant in Argentina's National Scientific and Technological System and is pioneer at an international level in terms of Antarctic research. The IAA is responsible for centralizing the planning, coordination and control of Argentine scientific activities in Antarctica, where approximately 60% of its projects include international scientific cooperation in association with National Antarctic Programs, as well as universities and research centers from more than 20 countries. The research priorities of the IAA include studies on marine ecosystems and resources, microbial communities, biology of top predators, eco-physiology and ecotoxicology, terrestrial ecosystems, human biology and psychology, southern hemisphere geology, cartography, Antarctic geophysics and geodesy, climate change, marine pollution, physical oceanography, high atmosphere and spatial climate, paleontology and social sciences including the longstanding presence and Argentine history in Antarctica.

More specifically, the IAA is presently focusing its research on global climate change, including past and present effects, and future projections on marine and terrestrial ecosystems; the conservation of Antarctic marine living resources by studying the structure and functioning of the ecosystems, monitoring key species and developing protected areas; studies of the physics and chemistry of the high atmosphere including research on the weather and the ozone layer health; Antarctic microbiology with biotechnological applications; and the geological evolution of the Antarctic Peninsula region; among others.

The IAA has an outstanding scientific production; participates in numerous international scientific conferences and forums, including providing advice to the Antarctic Treaty System; develops capacity building by promoting research careers and access to national and international scholarships; and participates in numerous outreach activities aimed to inspire and attract young future researchers to the Antarctic.

EXPLORING THE BIODIVERSITY

EXPLORING THE BIODIVERSITY OF THE ANTARCTIC PENINSULA: **ONE OF THE LAST OCEAN WILDERNESSES**

During our scientific expedition we surveyed a total of 14 stations (Figure 13; Table 1) across the Western Antarctic Peninsula (WAP), where the scientific team characterized biological communities using a combination of visual and photographic surveys using SCUBA, Deep Ocean Drop Cams and plankton nets. This bi-national expedition was conducted on the Chilean Navy vessel, the OPV-83 Marinero Fuentealba (Figure 14).

TABLE 1.

Locations sampled during the expedition.

Date	Island	Location	Station	Lat	Long
9-Jan-19	King George (25 de Mayo*)	Neebles Point, Fildérs Bay	1	-62.1845	-58.8547
10-Jan-19		Potter Cove, New Island	2	-62.2252	-58.6433
12-Jan-19		Potter Cove, Rocky Point	3	-62.2378	-58.7159
13-Jan-19	Deception	Whalers Bay	4	-62.9882	-60.555
13-Jan-19		Whalers Bay	5	-62.9913	-60.5622
15-Jan-19	Antarctic Peninsula, Danco Coast	Paradise Bay	6	-64.806	-62.8203
15-Jan-19		Paradise Bay, Brown Station	7	-64.8979	-62.873
16-Jan-19		Primavera Station, Cierva Cove	8	-64.1448	-60.9893
17-Jan-19	Antarctic Peninsula, Gerlache Strait	Wilhelmina Bay	9	-64.5829	-62.2029
17-Jan-19		Wilhelmina Bay	10	-64.5837	-62.1996
18-Jan-19		Cuverville Island	11	-64.6835	-62.6135
19-Jan-19	Deception	Whalers Bay	12	-62.9887	-60.5573
19-Jan-19		Roca Nueva	13	-63.0072	-60.7356
20-Jan-19	King George (25 de Mayo*)	Admiralty Bay	14	-62.166	-58.4385

FIGURE 13.

Sampling stations visited during the expedition aboard the OPV Marinero Fuentealba.

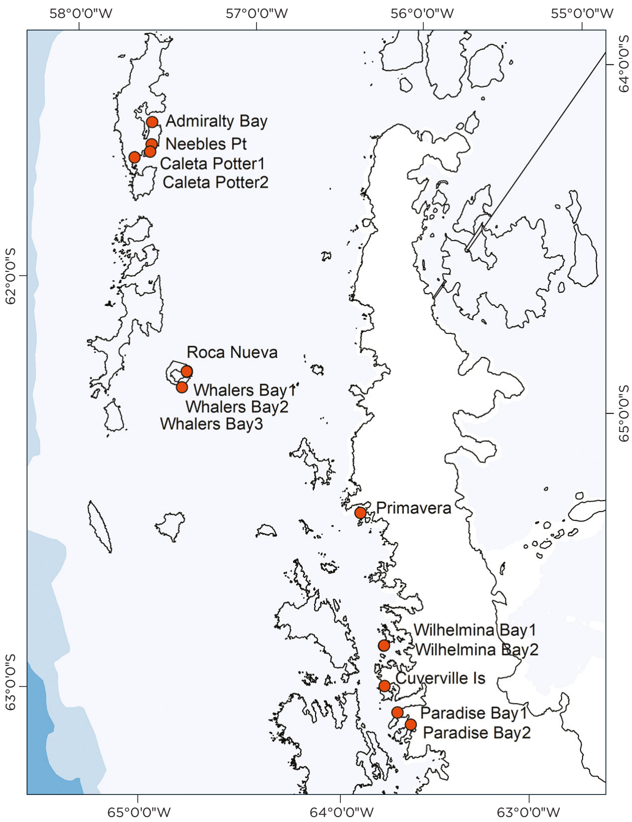


FIGURE 14.

The bi-national expedition was conducted aboard the Chilean Navy vessel OPV-83 Marinero Fuentealba. Jordi Chias/NGS.

2.1. Shallow Benthic Habitats

During our dive surveys we documented a wide variety of benthic communities that ranged from soft bottom habitats dominated by mobile macroinvertebratess to ice-free vertical walls dominated by a great diversity of sessile invertebrate species (Figure 15). Shallow water rocky reefs were characterized by the presence of algae-dominated benthic communities between 5 and ~ 25 m, with sponges and other filter-feeding organisms dominating diversity and abundance below 25–30 m depth (Barnes 1995, Cárdenas et al. 2016).

FIGURE 15.

Different benthic habitat types along the South Shetland Islands and the Western Antarctic Peninsula. A. soft bottom; B. macroalgae-dominated; C. ice-scour free areas- sponge, ascidians; D. rocky outcrops covered by anthozoans. Manu San Félix/NGS.

2.1.1. MACROALGAL BEDS

In general, the intertidal zone was almost devoid of macroalgae, although at some sampling stations there were small thin, green carpets that probably belonged to juvenile stages of *Urospora penicilliformis*, *Pyropia endiviifolia*, and *Ulothrix* sp. Tide pools were also devoid of well-developed macroalgae but—if not devoid of any algae—they hosted similar species to the intertidal (Figure 16).

The shallow subtidal zone (0 to 3–5 m depth) is heavily affected by ice scour. However, at some of the stations macroalgae development was observed. Encrusting coralline algae was abundant, in some cases covering nearly 100% of the hardbottom. These included several species of the genera *Hydrolithon*, *Lithothamnion*, and *Clathromorphum*, although proper identifications are still pending. Other algae species that co-occurred with these corallines included: *Adenocystis utricularis*, *Monostroma hariotii*, *Iridaea cordata*, *Curdiea racovitzae*, *Phaeurus antarcticus*, and *Palmaria decipiens*. Dominance of these macroalgae species differed between stations and is likely related to differences in the degree of ice abrasion or differences in exposure to swell (Figure 17). Grazing gastropods (sea snails) were common, mainly *Nacella concinna*, *Laevilacunaria antarctica*, and *Laeveilitorina caliginosa*. The chiton *Tonicina zschaui* was observed on a single occasion. Sessile macroinvertebrates were uncommon in this shallow subtidal zone.

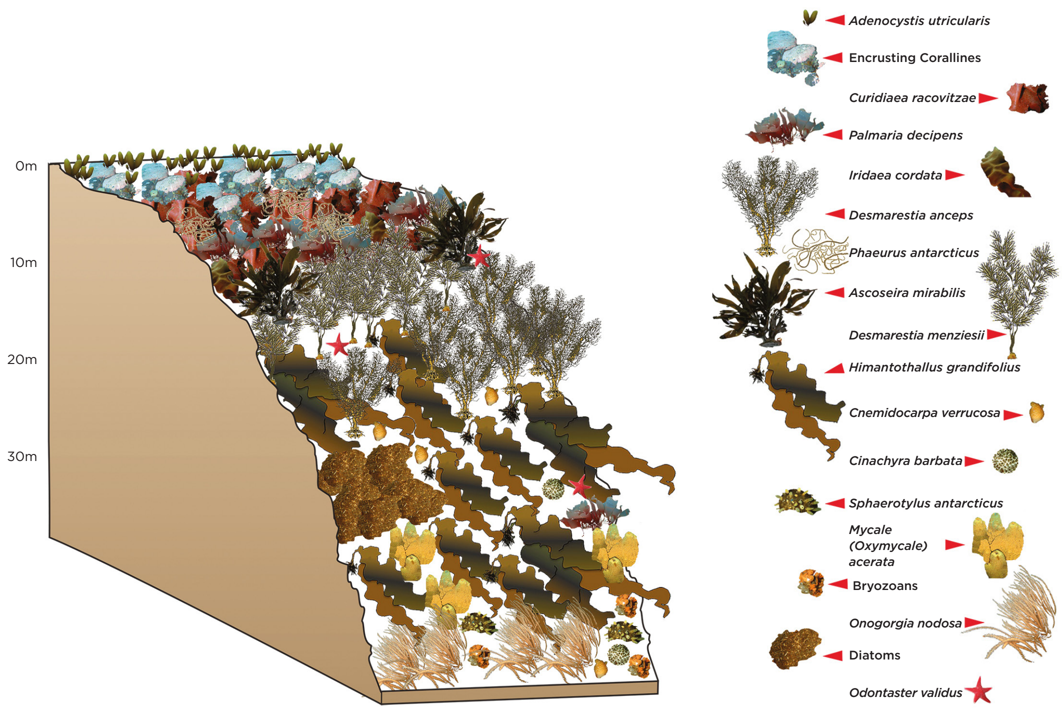


FIGURE 16.

Schematic representation of subtidal macroalgal communities across the Western Antarctic Peninsula. Source: María García/ CEAB CSIC.

FIGURE 17.

Macroalgae communities below the ice scour. Jordi Chias/NGS.

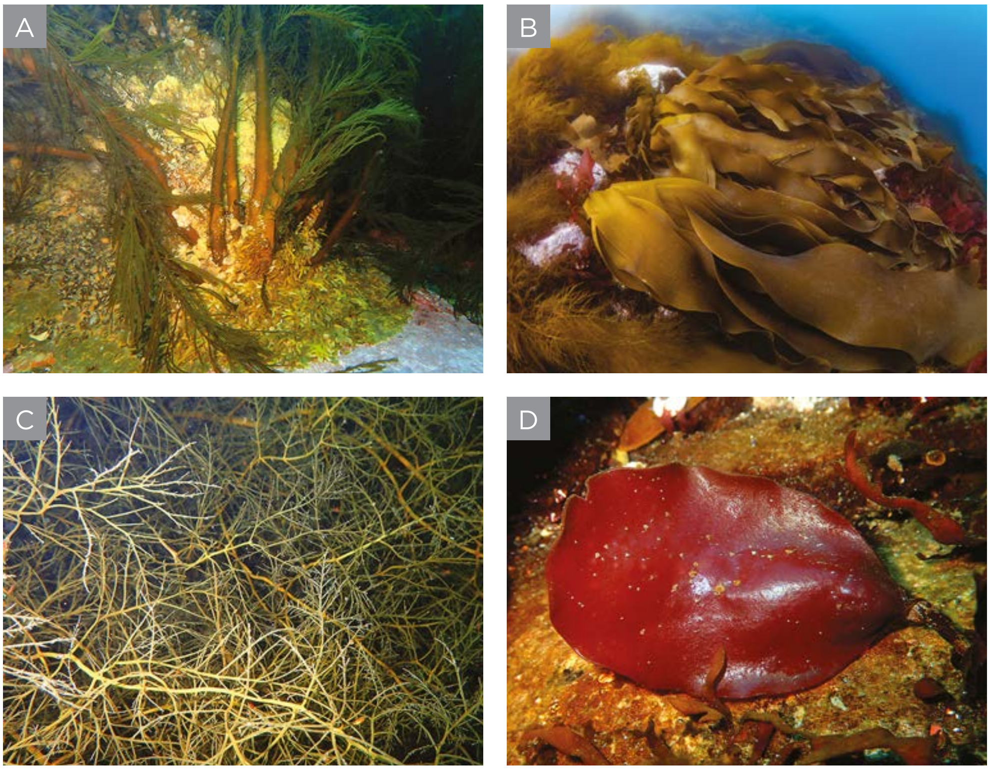
Below 3–5 m large brown macroalgae dominated the substrate. In depths <10 m the most abundant species was *Desmarestia menziesii*, which usually coexisted with other lesser abundant species such as *Ascoseira mirabilis*, *Desmarestia antarctica*, and *Desmarestia anceps* (Figure 18). The understory of this assemblage was rich in other macroalgae, mainly the same found in the ice scour zone, including crustose corallines. *Nacella concinna* was the most abundant gastropod but there were also other vagile species such as the sea stars *Anasterias antarctica*, *Neosmilaster georgianus*, and *Odontaster validus*, several species of amphipods, and some sponges such as *Polymastia invaginata*, *Sphaerotylus antarcticus*, and *Haliclona* sp. At the Wilhelmina Bay station, we also observed the Antarctic krill *Euphausia superba* in this type of habitat.

FIGURE 18.

Desmarestia menziesii was dominant in shallow (<10 m) rocky reefs. Jordi Chias/NGS.

At increasing depths *D. anceps* was progressively replaced by *D. menziesii*. The kelp-like macroalga *Himantothallus grandifolius* also became common, finally replacing *D. anceps* at around 20 m, and extending down to at least 35–40 m (Figure 19). *Cystosphaera jacquinotii* was observed only once at Napier Rock in Admiralty Bay (King George [25 de Mayo*] Island) at 30 m, creating a mixed assemblage with *Himantothallus grandifolius*. The understory of these *Himantothallus-Desmarestia* assemblages was extremely rich in macroalgae, but also in sessile and vagile macroinvertebrates (Figure 20).

FIGURE 19.



Dominant macroalgae. A. *Desmarestia anceps*; B. *Himantothallus grandifolius*; C. *Desmarestia menziesii*; D. *Iridaea cordata*. Kike Ballesteros/NGS.

FIGURE 20.

Rich invertebrate community underneath the algae canopy at depth. Manu San Félix/NGS.

Amongst the macroalgae, were red algae, primarily *Plocamium* sp., *Palmaria decipiens*, *Iridaea cordata*, *Sarcothalia papillosa*, *Gigartina skottsbergii*, *Phyllophora ahnfeltioides*, *Georgiella confluens*, *Pantoneura plocamioides*, *Trematocarpus antarcticus*, and *Gymnogongrus turquetii*, and the brown alga *Halopteris obovata* (Figure 21). Members of the red algal family Delesseriaceae (*Myriogramme manginii*, *Neuroglossum delesseriae*, and *Phycodrys austrogeorgica*) were observed in the understory of *Himantothallus elongatus*. The brown epiphyte *Geminocarpus austrogeorgiae* was common observed overgrowing *Himantothallus*.

FIGURE 21.

Red macroalgae growing among *Desmarestia*. Manu San Félix/NGS.

2.1.2. BENTHIC COMMUNITIES

Benthic communities show a high degree of patchiness in both diversity and abundance, with notable differences in areas of disturbance due to ice scour in the shallows. Hard bottom and soft sediment benthic communities within the region are known to be capable of supporting both extremes of diversity and biomass (Griffiths et al. 2010).

The 14 stations we surveyed had heterogeneous benthic communities that were highly influenced by the prevailing substrate. Sediment (22%) and barrens (4%) dominated at ~ 25% of the stations surveyed. The dominant sessile components of the hard-bottom benthic community consisted primarily of large brown macroalgae (*Desmarestia anceps* = 31%, *Himantothallus grandifolius* = 28%, *Desmarestia menziesii* = 4%). The ascidian *Cnemidocarpa verrucosa*, which accounted for 4% of total hard-bottom cover and the sponge *Mycale (Oxymycale) acerata*, which accounted for 2.3% of total hard-bottom were more abundant below 20 m (Figure 22).

FIGURE 22.

Rich invertebrate communities were recorded on hard substrate.

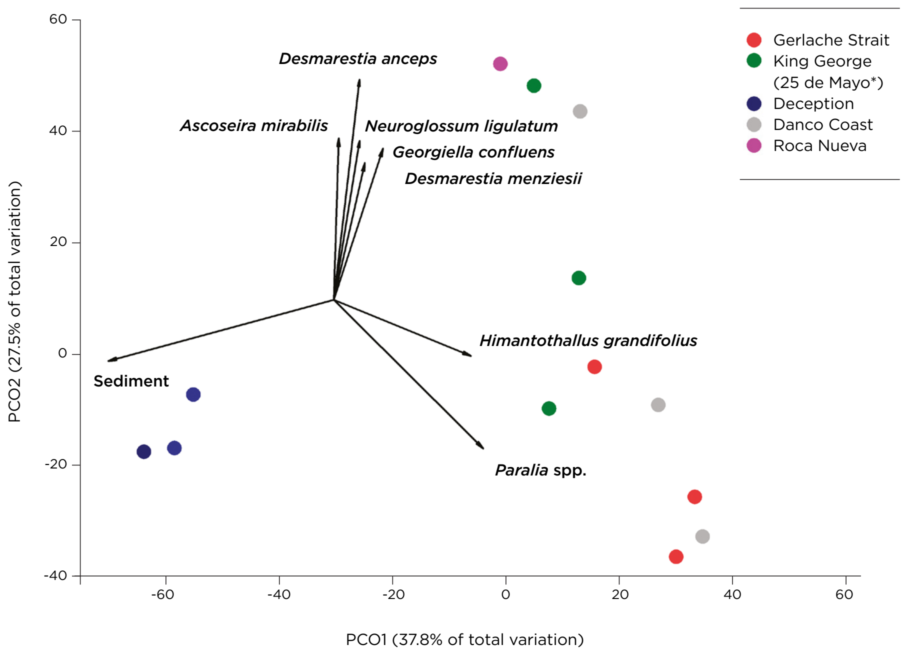
Primary producers comprised 88% of total sessile benthic cover, followed by suspension feeders (11%), and deposit feeders (~1%). The Antarctic benthic communities have structural similarity with the Paleozoic biota, the archaic biota of deeper waters: communities dominated by sessile suspension feeders that form complex three-dimensional biogenic structures, seated on soft bottoms (Clarke et al. 2005, Gili et al. 2006). There is a tendency towards gigantism among sponges, sea spiders, isopods, and ribbon worms, many of which are endemic (Clarke & Johnston 2003) (Figure 23). Sessile benthic communities clustered into three separate groups: hard-bottom habitats dominated by *Himantothallus grandifolius* and the chain-forming diatom *Paralia* sp., hard-bottom communities with diverse brown macroalgae, and soft bottoms (Figure 24).

FIGURE 23.

Sea spider *Austropallene cristata*. Jordi Chias/NGS.

FIGURE 24.

Principal component analysis of macroalgal communities by station.



Himantothallus, and to a lesser extent *Desmarestia anceps* forests hosted a wide array of macroinvertebrates in the understory. Common sponges were *Mycale (Oxymycale) acerata*, *Sphaerotylus antarcticus*, *Polymastia invaginata*, *Cinachyra barbata*, *Dendrilla antarctica*, several unidentified *Haliclona* spp. and *Isodyctia* spp. The most common cnidaria were *Alcyonium antarcticum*, *Onogorgia nodosa* and *Hormosoma scotti*, while different unidentified species of bryozoans were abundant in some places (Figure 25).

FIGURE 25.

Understory of *Desmarestia anceps* with a rich invertebrate community. Manu San Felix/NGS.

Tunicates *Cnemidocarpa verrucosa*, *Molgula pedunculata*, *Corella antarctica*, *Aplidium falklandicum*, *A. loricatum*, *Synoicum adareanum*, and *Synoicum georgianum* were frequently observed in this habitat. Terebellidae worms were abundant in sheltered environments, with reduced water movement. The most common vagile species were sea stars, mainly *Odontaster validus*, *Labidiaster annulatus*, *Anasterias antarctica*, *Neosmilaster georgianus*, *Perknaster* spp., *Acodontaster hodgsoni*, *Diplasterias brucei*, and *Odontaster meridionalis*. Other echinoderms were sea cucumbers *Heterocucumis steineni* and *Cucumaria attenuate*, sea urchin *Sterechinus neumayeri* and crinoid *Promachocrinus kerguelensis*. Amphipods were extremely abundant as well as the limpet *Nacella concinna* and the snail *Margarella antarctica* (Figure 26).

Crevices and overhangs present in the *Himantothallus-Desmarestia* forests were dominated by macroinvertebrates, mainly the sponges and ascidians mentioned above but also other species, mainly bryozoans and encrusting sponges (Figure 27).

FIGURE 26.

A diverse community of sponges and tunicates. Manu San Felix/NGS.

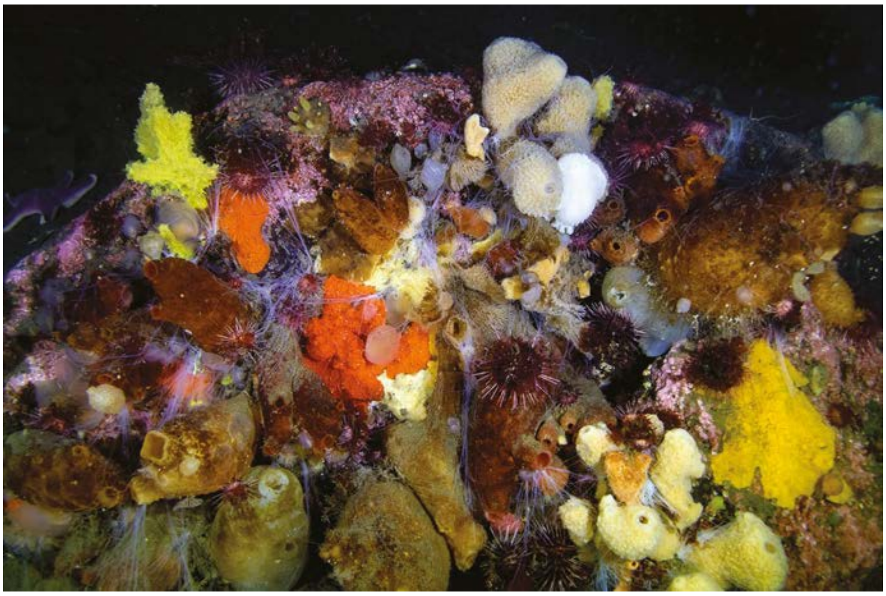


FIGURE 27.

Vertical walls free of ice scour harbour diverse invertebrate communities. Manu San Felix/NGS.

At some of the stations, the assemblages dominated by *D. anceps* and *H. grandifolius* were replaced or coexisted with carpets of benthic filamentous diatoms (mainly *Paralia* sp. but also other species such as *Triceratium* sp.). These diatom-dominated assemblages were frequent on steep walls. Macroinvertebrates were less common here than in *Himantothallus-Desmarestia* forests although ascidians were occasionally abundant, together with *Mycale (Oxymycale) acerata* and Terebellidae worms.
Two sea slugs were observed within these massive diatom blooms, *Pseudotritonia gracilidens* and *P. quadrangularis*. Sea stars were also occasionally observed within this habitat (*Odontaster validus*, *Labidiaster annulatus*, *Neosmilaster georgianus*, *Anasterias antarctica*) (Figure 28).

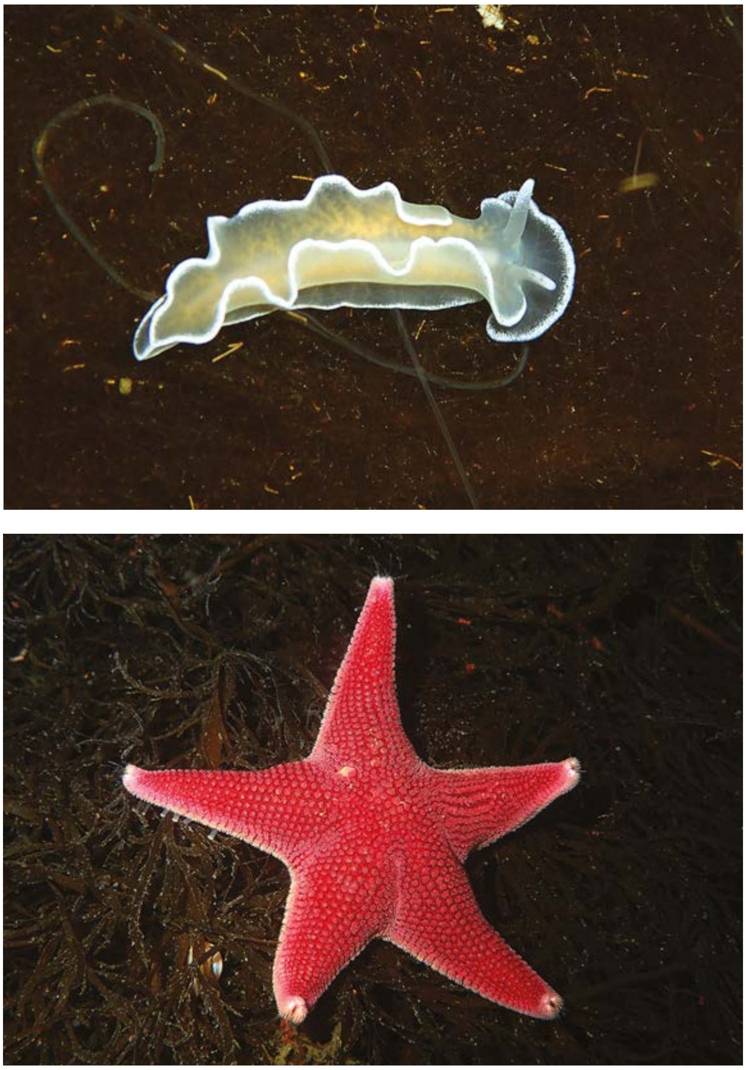


FIGURE 28.

The sea slug *Pseudotritonia gracilidens* and the sea star *Odontaster validus*. Kike Ballesteros/NGS.

At Potter Cove (King George [25 de Mayo*] Island) and Whalers Bay (Deception Island), the assemblages were almost devoid of macroalgae and dominated by invertebrates on hard substrate. At a small island in Potter Cove very close to a glacier, the assemblage was dominated by the solitary ascidians *Cnemidocarpa verrucosa*, *Molgula pedunculata*, *Ascidia challengeri*, and *Corella antarctica*; sponges *Mycale (Oxymycale) acerata* and *Haliclona* spp., an unidentified polychaete (Terebellidae), the anemone *Hormosoma scotti*, the pennatulid *Malacobelemnon daytoni* in places with soft sediment, the benthic ctenophore *Lyrocteis flavopallidus* and filamentous diatoms (*Paralia* sp.). At Deception island the dominances corresponded to encrusting coralline algae, sponges *Mycale (Oxymycale) acerata*, *Dendrilla antarctica*, *Kirkpatrickia variolosa*, *Haliclona* spp., *Polymastia invaginata*, tunicates *Molgula pedunculata*, and *Cnemidocarpa verrucosa*, a Terebellidae worm and anthozoans, *Hormosoma scotti* and *Calvularia* sp. The most common vagile species were unidentified amphipods, sea stars *Odontaster validus* and *Perknaster* sp., ribbon worm *Parborlasia corrugatus*, sea urchin *Sterechinus neumayeri*, brittle star *Ophionotus victoriae*, and limpet *Nacella concinna* (Figure 29).

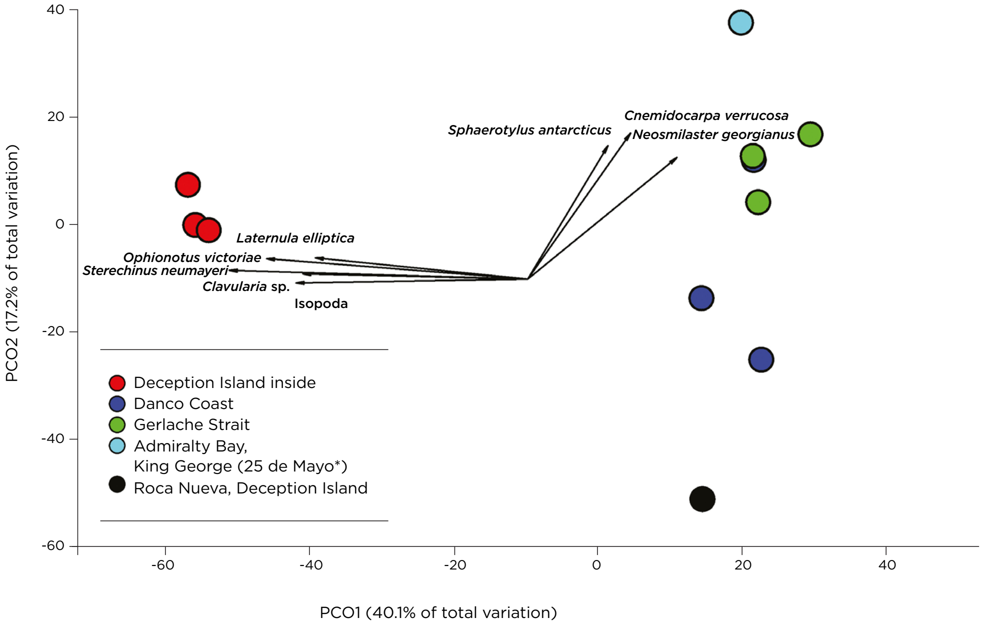
FIGURE 29.

Macroinvertebrate dominated assemblages at Deception Island. Manu San Felix/NGS.

Examination of benthic invertebrate communities based on photo-quadrats showed strong separation between the community inside Deception Island and the other sampling locations (Figure 30). The community inside Deception Island showed high concordance among sites, which was driven by the presence of the bivalve *Laternula elliptica*, the brittlestar *Ophionotus victoriae*, the sea urchin *Sterechinus neumayeri*, the soft coral *Clavularia* sp., and isopods. The tunicate *Cnemidocarpa verrucosa*, the seastar *Neosmilaster georgianus*, and the sponge *Sphaerotylus antarcticus*, were correlated with stations along Gerlache Strait and Napier Rock, Admiralty Bay (King George [25 de Mayo*] Island).

FIGURE 30.

Principal coordinates analysis of invertebrate abundance per sampling station.



Deep-water (>35 m) coastal assemblages have been seldom surveyed to date due to logistical constraints. These environments are devoid of a brown algal canopy and although there are some corallines and erect laminar red algae (*Neuroglossum delesseriae*, *Phycodrys quercifolia*, and others), dominance corresponds to macroinvertebrates. Walls at 50–60 m in Paradise Bay are completely dominated by sponges, most of them the same that are found in shallower waters but also large specimens of *Anoxycalyx joubini*, which are normally not found in shallow waters due to the influence of ice-scour (Figure 31). In contrast, steep, almost vertical walls at Napier Rock (King George [25 de Mayo*] Island) were dominated by gorgonians (*Onogorgia nodosa*, *Thouarella crenelata*, *T. pendulina*) together with erect bryozoans, ascidians, and sponges.

FIGURE 31.

Large sponges *Anoxycalyx (Scolymastra) joubini* (up to 2 m across) were present at deeper depths (>50 m) at Paradise Bay. Jordi Chias/NGS.

Sedimentary bottoms were only surveyed at Whalers Bay (Deception Island). In shallow waters (3–5 m depth) there was a mixture of gravel and mud, with an assemblage dominated by amphipods, the isopod *Serolis* sp., small anemones, and bivalves *Laternula elliptica* and *Yoldia eightsii*. In deeper waters, down to 20 m depth, the sediment was muddier, the abundances of *Edwardsia*, *Laternula*, and *Yoldia eightsii* progressively decreased and the assemblage became dominated by the brittle star *Ophionotus victoriae* (129 ind·m^{-2}), the sea urchin *Sterechinus neumayeri* (39 ind·m^{-2}) and the sea star *Odontaster validus* (3.5 ind·m^{-2}) (Figure 32).

FIGURE 32.

Sedimentary bottom at Whalers Bay, Deception Island, dominated by the brittle star *Ophionotus victoriae*. Manu San Félix/NGS.

TABLE 2.

Top 15 benthic taxa observed on transects. PP = primary producers.

Accepted name	Phylum (Division)	Class	Order	Family	Funct. Grp	Cover (sd)	Freq	Percent total
Desmarestia anceps	Ochrophyta	Phaeophyceae	Desmarestiales	Desmarestiaceae	PP	16.3 (28.7)	30.8	31.1
Himantothallus grandifolius	Ochrophyta	Phaeophyceae	Desmarestiales	Desmarestiaceae	PP	14.6 (23.7)	61.5	27.9
CCA = crustose coralline algae	Rhodophyta	Florideophyceae	Corallinales		PP	3.5 (5.9)	46.2	6.7
Cnemidocarpa verrucosa	Chordata	Ascidiacea	Stolidobranchia	Styelidae	Suspension	2.3 (7.2)	30.8	4.4
Desmarestia menziesii	Ochrophyta	Phaeophyceae	Desmarestiales	Desmarestiaceae	PP	2.1 (4.8)	23.1	3.9
Halopteris obovata	Ochrophyta	Phaeophyceae	Sphacelariales	Stypocaulaceae	PP	2 (7.1)	7.7	3.8
Iridaea cordata	Rhodophyta	Florideophyceae	Gigartinales	Gigartinaceae	PP	1.4 (2)	53.9	2.7
Mycale (Oxymycale) acerata	Porifera	Demospongiae	Poecilosclerida	Mycalidae	Suspension	1.2 (1.4)	53.9	2.3
Plocamium hookeri	Rhodophyta	Florideophyceae	Plocamiales	Plocamiaceae	PP	1 (2.5)	23.1	1.9
Ballia callitricha	Rhodophyta	Florideophyceae	Balliales	Balliaceae	PP	0.9 (2.1)	23.1	1.6
Desmarestia antarctica	Ochrophyta	Phaeophyceae	Desmarestiales	Desmarestiaceae	PP	0.9 (1.6)	30.8	1.6
Ascoseira mirabilis	Ochrophyta	Phaeophyceae	Ascoseirales	Ascoseiraceae	PP	0.7 (1.8)	15.4	1.3
Terebellidae	Annelida	Polychaeta	Canalipalpata	Terebellidae	Deposit	0.6 (2.2)	7.7	1.2
Neuroglossum delesseriae	Rhodophyta	Florideophyceae	Ceramiales	Delesseriaceae	PP	0.6 (1.4)	23.1	1.2
Georgiella confluens	Rhodophyta	Florideophyceae	Ceramiales	Callithamniaceae	PP	0.6 (1.2)	23.1	1.1

2.1.3. SHALLOW FISH COMMUNITIES

We conducted surveys at 14 stations at depths ranging from 6 to 29 m within the South Shetland Islands and the Antarctic Peninsula (South Shetland Islands = 8 and Antarctic Peninsula = 6). A total of 7 species of fishes from 3 families and 1 order were observed during shallow water (<30 m) surveys, with the average size of all species combined only 26.4 cm TL (± 12.8) (Table 3). The dragon fish (*Parachaenichthys charcoti*, n = 6, 44 ± 5.5 cm TL), the blackfin icefish (*Chaenocephalus aceratus*, n = 1, 40 cm TL) and the bullhead notothen (*Notothenia coriiceps*, n = 17, 31.4 ± 11.8 cm TL) were the only three species larger than 30 cm TL observed during the quantitative underwater surveys (Figure 33).

FIGURE 33.

(A) The dragon fish, *Parachaenichthys charcoti*. (B) The bullhead notothen, *Notothenia coriiceps*. Manu San Félix/NGS.

Nototheniidae was the most specious family, accounting for 71.4% of all species observed (Table 3). The dusky notothen (*Trematomus newnesi*) showed the highest frequency of occurrence (50%), followed by the gaudy notothen (*Lepidonotothen nudifrons*) and the bullhead notothen (*N. coriiceps*), both with 35.7% of occurrence (Table 4, Figure 34). The most abundant species was *N. coriiceps*, followed by *T. newnesi* with 17 and 9 individuals, respectively.

TABLE 3.

Shallow water fish species observed during the quantitative underwater surveys along the Antarctic Peninsula and South Shetland Islands. Mean total length (TL) in cm.

Order	Family	Species	Mean TL (sd)
Perciformes	Nototheniidae	*Lepidonotothen nudifrons*	14.5 (1.7)
		Lepidonotothen sp.	15
		Notothenia coriiceps	31.4 (11.8)
		Pagothenia borchgrevinki	20
		Trematomus newnesi	19.2 (4.0)
	Bathydraconidae	*Parachaenichthys charcoti*	44 (5.5)
	Channichthyidae	*Chaenocephalus aceratus*	40

TABLE 4.

Sampling stations (1 to 14) abundance of fish species, percent of frequency of occurrence (F) and number of individuals per species (N).

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	N	F
Lepidonotothen nudifrons	1	1						1				1	1		5	35.7
***Lepidonotothen* sp.**											1				1	7.14
Notothenia coriiceps	1		2						1	1			12		17	35.7
Pagothenia borchgrevinki									1						1	7.14
Trematomus newnesi						2			1	1	1	1	2	1	9	50
Parachaenichthys charcoti				1	1				1			3			6	28.6
Chaenocephalus aceratus									1						1	7.14
Total individuals	2	1	2	1	1	2	0	1	5	2	2	5	15	1	40	

Species endemic to the Scotia Arc and Antarctic Peninsula accounted for 50% of the nearshore species observed (Table 4), followed by species with Circum-Antarctic distribution. Species with benthic habitat preferences accounted for 83.3% of the observed nearshore fishes, followed by bentho-pelagic species, *Trematomus newnesi*. Most of the fishes observed were invertebrate feeders, while two fed on fishes and invertebrates (e.g., bullhead notothen and dragon fish) (Table 5).

FIGURE 34.

Trematomus newnesi (A) was the most common observed species, followed by *Lepidonotothen nudifrons* (B), and *Notothenia coriiceps* juveniles (C) and adults (D).

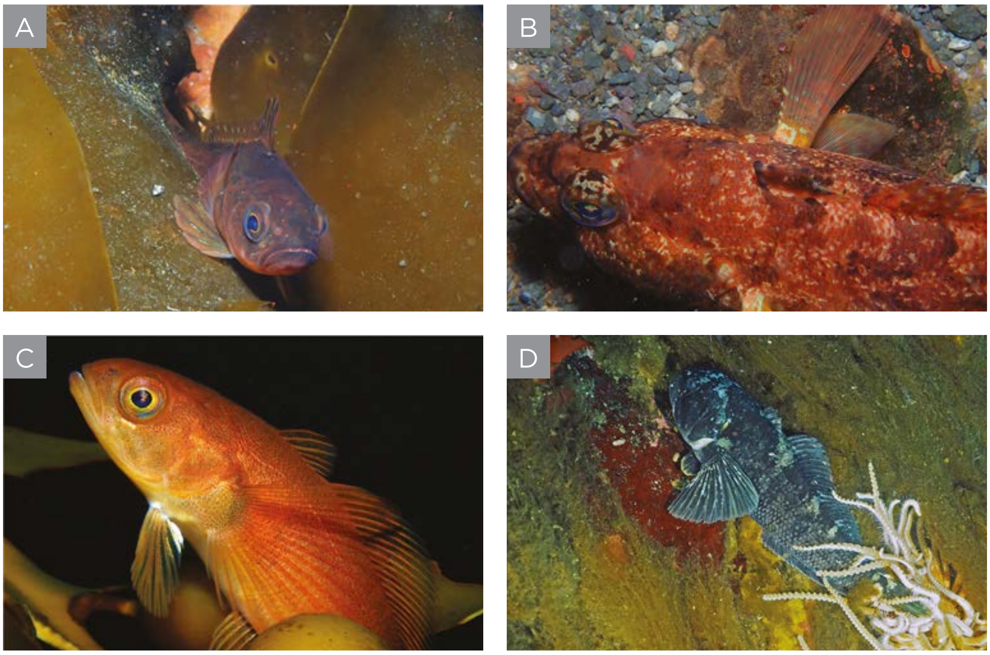


TABLE 5.

Species of fishes observed during the expedition to the Antarctic Peninsula and South Shetland Islands in Austral summer of 2019.

Family name	Common name	Scientific name	Trophic group	Habitat	Dist.	Depth limit[b,] (m)
Nototheniidae	Gaudy notothen	*Lepidonotothen nudifrons*	Inv	Benthic	Scotia Arc, Antarctic Pen.	5–350
	Bullhead notothen	*Notothenia coriiceps*	Omn	Benthic	Circum-Antarctic	0–550
	Bald notothen	*Pagothenia borchgrevinki*	Inv	Cryope lagic, Benthic	Circum-Antarctic	0–30
	Dusky notothen	*Trematomus newnesi*	Inv	Bentho-pelagic	Circum-Antarctic	0–400
Bathydraconidae	Dragon fish	*Parachaenichthys charcoti*	Omn	Benthic	Scotia Arc, Antarctic Pen.	5–480
Channichthydae	Blackfin icefish	*Chaenocephalus aceratus*	Pisc	Benthic	Scotia Arc, Antarctic Pen.	5–770

[a]Gon & Heemstra 1990; [b]Eastman 2017; Pisc, piscivore; Inv, invertivore; Omn, Omnivore

There were differences in the fish assemblages between stations in ordination space, with PCO1 explained nearly 41% of the total variation among South Shetland Islands (King George [25 de Mayo*], Deception, and Roca Nueva) and Antarctic Peninsula (Gerlache Strait and Danco Coast) (Figure 35). These differences were driven by the dusky notothen *T. newnesi* and the bullhead notothen *N. coriiceps*. PCO2 explained an additional 34.1% of the variation, with the strongest separation between Deception Island and the other stations. The dragon fish *Parachaenichthys charcoti* drove the separation of Deception Island.

FIGURE 35.

Principal coordinates analysis of fish species numerical abundance by station.

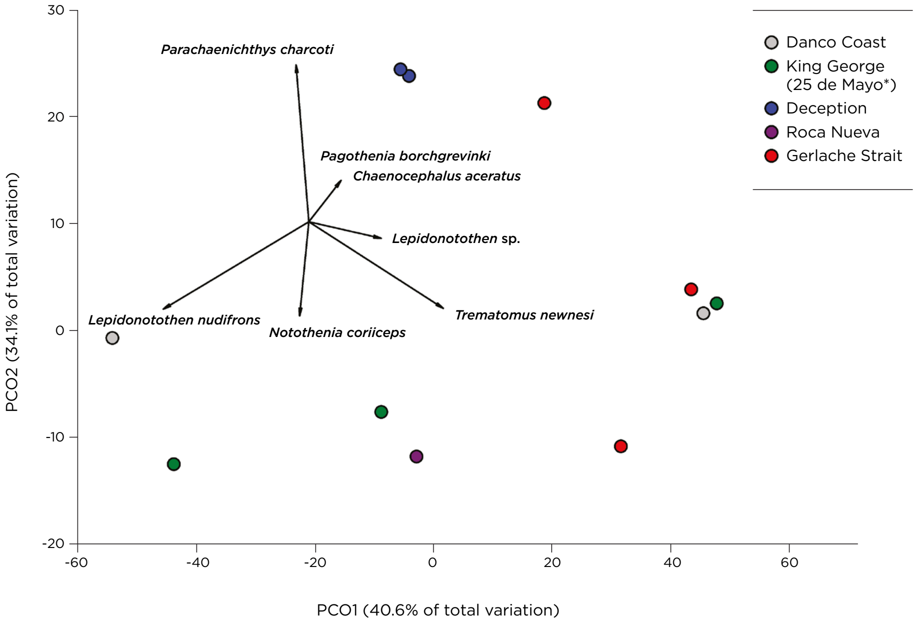


TABLE 6.

Similarity of percentages (SIMPER) for fish species most responsible for the percent dissimilarities between sub-regions (South Shetland Islands: King George (25 de Mayo*), Deception and Roca Nueva; Antarctic Peninsula: Gerlache Strait and Danco Coast) using Bray-Curtis similarity analysis of hierarchical agglomerative group average clustering.

Dissimilarity = 74.3	SSI.	AP.	Diss.	%Diss.
Trematomus newnesi	0.43	0.88	19.7 (1.0)	26.48
Notothenia coriiceps	0.73	0.40	17.0 (0.9)	22.91
Parachaenichthys charcoti	0.47	0.20	13.2 (0.8)	17.76
Lepidonotothen nudifrons	0.50	0.20	13.1 (0.8)	17.63

SSI. = South Shetland Islands; AP. = Antarctic Peninsula; Diss. = Average dissimilarity with one standard deviation of the mean in parentheses.

The dissimilarity in the fish assemblages between South Shetland Islands and Antarctic Peninsula was 74.3%, which was primarily driven by the density of *T. newnesi* at Antarctic Peninsula and *N. coriiceps* at South Shetland Islands (Table 6). The comparison between the sub-regions (South Shetland Islands and Antarctic Peninsula) did not show a significant difference in the fish assemblages (PERMANOVA, $F = 0.44$, $P = 0.97$), supporting the existence of the absence of significant difference in the nearshore fish assemblages from the coastal ecosystem of South Shetland Islands and Antarctic Peninsula.

2.2. Deep-sea Communities

Over 90% of the region is > 1,000 m deep, but benthic sampling has been largely restricted to the shelf. Therefore, little is known about the fauna of the deep sea. The location of scientific bases heavily influences the distribution pattern of samples and observation data, and the logistical supply routes to the stations are the focus of much of the at-sea and pelagic work (Griffiths, et al. 2010).

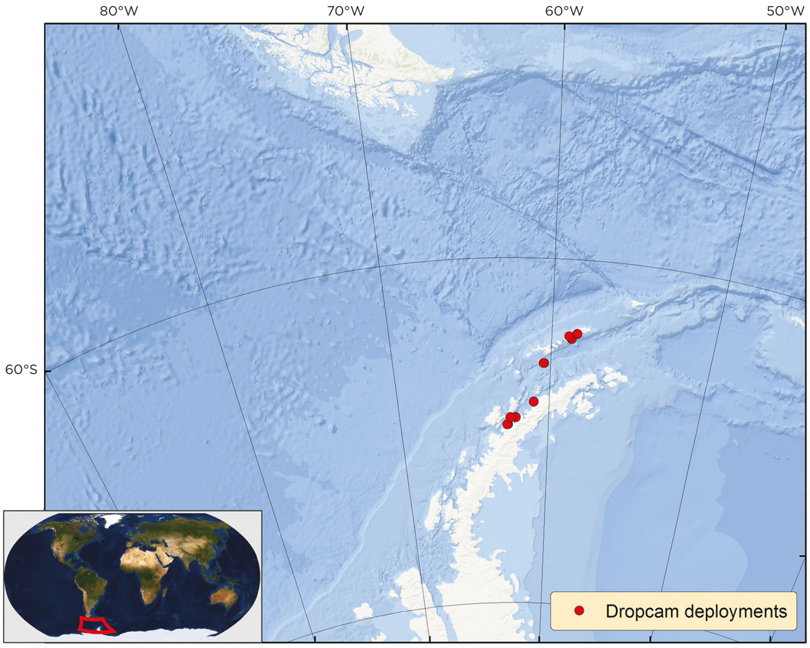
National Geographic's Exploration Technology Lab developed Deep Ocean Dropcams to observe deep-sea life in situ by capturing high quality imagery of the sea floor (Turchik et al. 2015). Deep-Ocean Dropcams house a Sony Handycam FDR-AX33 4K Ultra-High Definition video with a 20.6 megapixel still image capability (Figure 36). This is encased in a 33-cm diameter borosilicate glass sphere and rated to 7,000 m depth. Viewing area per frame is between 2–6 m^2, depending on the steepness of the slope where the Dropcam lands.

FIGURE 36.

Deploying a Deep Ocean Dropcam. Manu San Félix/NGS.

A total of 24 successful deployments of the Deep Ocean Dropcam were conducted in January 2019 (Figure 37). Cameras were baited with 500 g of frozen fish and deployed for 6 to 9 hrs. Lights and camera were programmed to periodically turn off. Between two to four total hours of video footage was recorded for each drop. Deployment depths ranged from 90 to 797 m (mean = 394 m) (Table 8). Video footage was annotated for taxa present (identified to the lowest possible taxonomic level) and maximum number of individuals of a given taxon per video frame (MaxN). Frequency of occurrence (Freq. occ. %) for each taxon observed was calculated as the percent of incidence over 24 successful deployments.

FIGURE 37.



Deep Ocean Dropcam deployment locations.

TABLE 8.

Metadata from Deep Ocean Dropcam deployments.

Location	N	Average Depth (m)	Std Dev Depth	Max Depth
Antarctic Peninsula	16	417.77	251.80	797
Deception Island	4	374.54	162.69	599
King George (25 de Mayo*) Island	5	311.22	199.22	485
Total	**25**	**389.54**	**226.71**	**796.97**

Fishes

Taxonomic diversity of fishes is relatively limited in Antarctic waters. An average of 3.2 (± 1.4 sd) different families of fishes per deployment were observed on Deep Ocean Dropcam footage. Crocodile icefishes (Channichthyidae) were the most commonly occurring fish family, observed on nearly 90% of the deployments. Barracudinas (Paralepididae; were also common, observed on 68% of deployments (Figure 38). Cod icefishes (Nototheniidae) and Lanternfishes (Myctophidae) occurred on 47% and 42% of deployments, respectively. While Crocodile icefishes and Cod icefishes were observed across the depths sampled (90 to 797 m), Lanternfishes were observed only in depths greater than 374 m, and Barracudinas only deeper than 300 m.

Lanternfishes (Myctophidae) and Barracudinas (Paralepididae) were the most abundant, both with MaxN values up to 10 individuals per frame. Crocodile icefishes (Channichthyidae) and Cod icefishes (Nototheniidae) reached their highest MaxN values at 5 and 4 individuals per frame, respectively (Table 9). Rare sightings included a McCain's skate (*Bathyraja maccaini*, Family: Arhynchobatidae) and an Antarctic dragonfish (Family: Bathydraconidae), seen at 599 and 301 m depth, respectively (Figure 38).

FIGURE 38.

Commonly occurring fish observed on Deep Ocean Dropcams included (A) Barracudinas (foreground; Family: Paralepididae) and Crocodile icefishes (center; Family: Channichthyidae). (B) McCain's skate (Bathyraja maccaini, Family: Arhynchobatidae); and (C) Antarctic dragonfish (Family: Bathydraconidae).

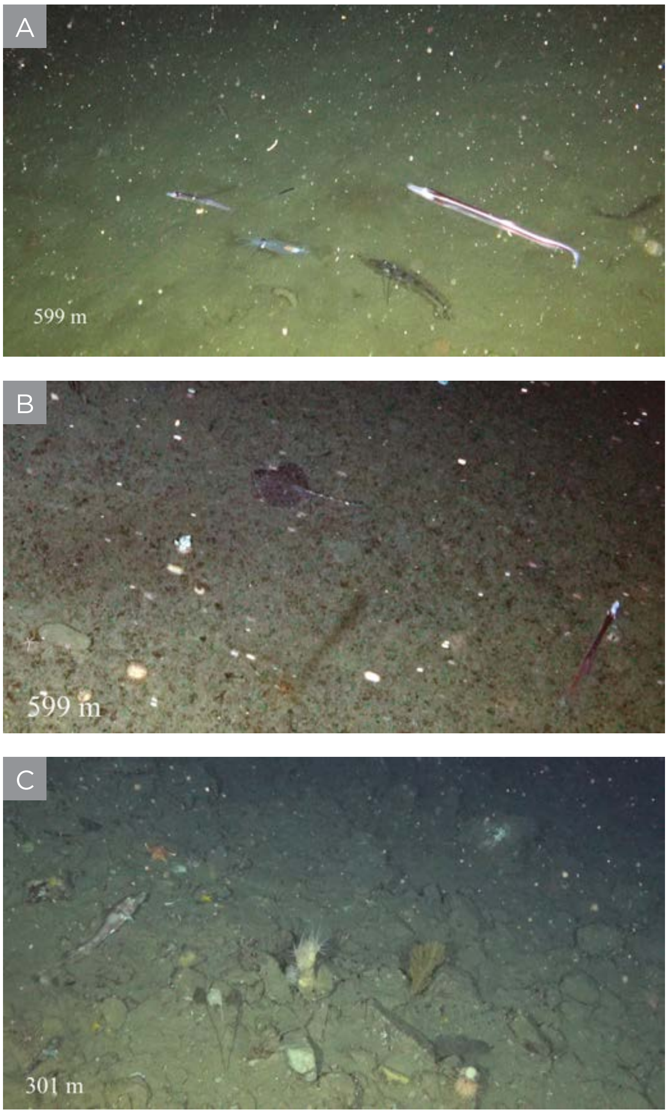


TABLE 9.

Frequency of occurrence (%) and MaxN (maximum individuals per frame) of fish taxa observed in Deep Ocean Dropcam deployments.

Class	Order	Family	Freq. occ (%)	MaxN
Actinopterygii	Aulopiformes	Paralepididae	68	10
		Notolepis coatsi		
	Myctophiformes	Myctophidae	42	10
		Gymnoscopelus sp.		
	Perciformes	Bathydraconidae	5	1
		Chionodraco rastrospinosus		
		Parachaenichthys charcoti		
		Channichthyidae	89	5
		Notothenia nudifrons		
		Pagetopsis macropterus		
		Nototheniidae	47	4
		Lepidonotothen squamifrons		
		Lepidonotothen sp.		
		Notothenia nudifrons		
		Trematomus sp.		
Elasmobranchii	Rajiformes	Arhynchobatidae	5	1
		Bathyraja maccaini		

Invertebrates

Mobile invertebrates encountered in the deep-ocean video footage included amphipods, krill, squid, arrow worms, sea stars (Class: Asteroidea), brittle stars (Order: Ophiurida), deep-sea sea cucumbers, and sea urchins (Class: Echinoidea) (Figure 39). Krill (Order: Euphausiacea) were the most prevalent and abundant taxa of invertebrates, observed on every deployment, at times with over 100 individuals per frame. Most of these krill were *Euphausia superba*, but other species such as *Euphausia crystallophias* were observed. Arrow worms (Phylum: Chaetognatha) and amphipods (Order: Amphipoda) were also frequently occurring, observed on 65% and 60% of the deployments, respectively. Squid (Order: Oegopsida) were observed on 50% of the deployments, generally with a MaxN of 1 individual per frame, but observed at times with MaxN of up to 4 individuals per frame (Figure 40). Amphipods reached MaxN of up to 90, and brittle stars up to 60 individuals per frame. The deep-sea sea cucumbers (*Peniagone* sp., Order: Elasipodida) occurred on 25% of deployments, with up to 8 individuals per frame (Table 10).

FIGURE 39.

Diverse benthic assemblage at 198 m. 1. Brittle star cf. Ophiosparte gigas (Family: Ophiopyrgidae), 2. Brittle star Ophionotus victoriae (Family: Ophiuridae), 3. Sea urchin *Ctenocidaris perrieri* (Family: Ctenocidaridae), 4. Stalked ascidian (VME taxa; *Pyura bouvetensis*), 5. Sea star Acodontaster sp. (Family: Odontasteridae).

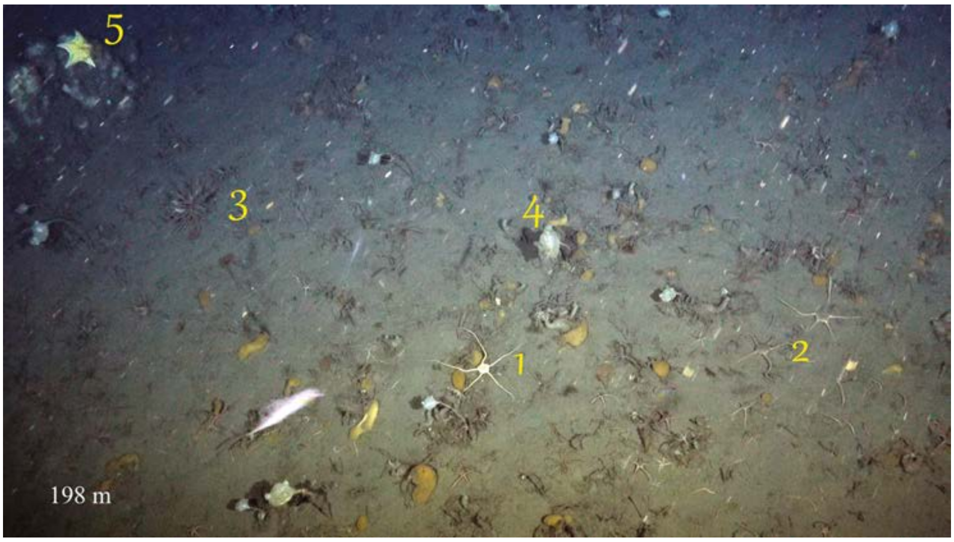


FIGURE 40.

Squid (Order: Oegopsida) were observed on over half of the Deep Ocean Dropcam deployments.

We identified a number of taxa that are classified at Vulnerable Marine Ecosystem (VME) taxa (Figure 41). These include cold water corals and sponge fields, which provide important habitat for a diversity of marine organisms. Sea urchin (Order: Cidaroida, probably *Ctenocidaris perrieri*), sea fan (Family: Primnoidae), and the large sponge *Rossella nuda*, all VME taxa, were observed on camera drops.

FIGURE 41.

1. *Ctenocidaris perrieri* (VME taxa), 2–4. Cod icefish (Family: Nototheniidae), 5. Seastar *Porania* sp. 6. Stalked ascidian (VME species; *Pyura bouvetensis*), 7. Gorgonian fan (Family: Primnoidae VME taxa), and 8. sea urchin (*Sterechinus neumayeri*).

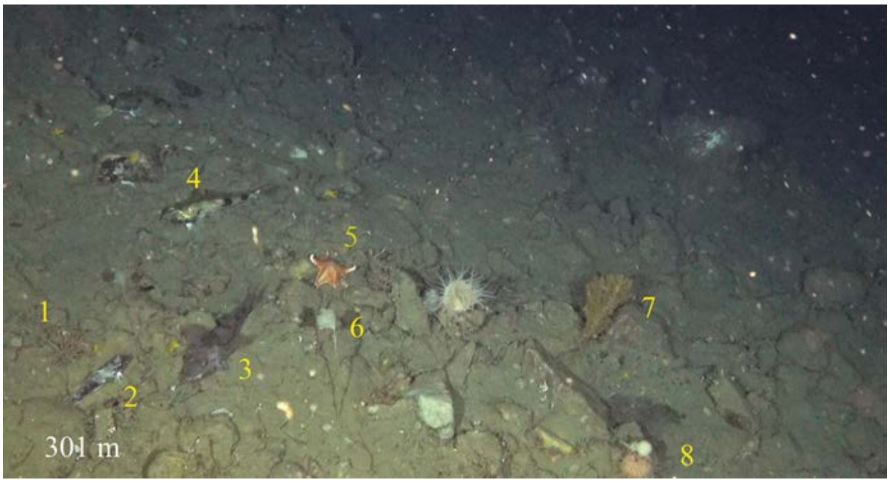


TABLE 10.

MaxN (maximum individuals per frame) and frequency of occurrence (%) of mobile invertebrate taxa observed in Deep Ocean Dropcam deployments.

Phylum	Class	Order	Freq. occ (%)	MaxN
Annelida	Polychaeta	Phyllodocida	25	3
		Tomopteridae		
		Tomopteris sp.		
Arthropoda	Malacostraca	Amphipoda	60	90
		Euphausiacea	95	120
		Euphausiidae		
		Euphausia crystallorophias		
Chaetognatha	Sagittoidea	Phragmophora	65	2
		Eukrohniidae		
		Eukrohnia hamata		
Chordata	Ascidiacea	Stolidobranchia	20	10
		Pyuridae		
		Pyura bouvetensis		
		Pyura setosa		
Cnidaria	Anthozoa	Actiniaria	5	2
		Edwardsiidae		
		Alcyonacea	20	40
		Primnoidae		
	Hydrozoa	Anthoathecata	15	10

Cnidaria		Siphonophora	**10**	**1**
		Trachymedusae	**15**	**1**
		Ptychogastriidae		
		Ptychogastria polaris		
Ctenophora	Nuda	Beroida	**5**	**1**
		Beroidae		
		Beroe cucumis		
	Tentaculata	Platyctenida		
		Lyroctenidae		
		Lyrocteis flavopallidus		
Echinodermata	Asteroidea	Valvatida	**10**	**1**
		Odontasteridae		
		Acodontaster sp.		
		Poraniidae		
		Porania antarctica		
	Echinoidea	Camarodonta	**5**	**1**
		Echinidae		
		Sterechinus neumayeri		
		Cidaroida	**30**	**3**
		Ctenocidaridae		
		Ctenocidaris perrieri		
	Holothuroidea	Elasipodida	**25**	**8**
		Elpidiidae		
		Peniagone sp.		
	Ophiuroidea	Ophiurida	**55**	**60**
		Ophiopyrgidae		
		Ophionotus victoriae		
		Ophiuridae		
		Ophionotus victoriae		
		Ophiosparte gigas		
Mollusca	Cephalopoda	Octopoda	**5**	**1**
		Oegopsida	**50**	**4**
Nemertea	Pilidiophora	Heteronemertea	**11**	**2**
		Lineidae		
		Parborlasia corrugatus		
Porifera	Hexactinellida	Lyssacinosida	**5**	**1**
		Rossellidae		
		Rossella nuda		

2.3. Birds

With over 45 bird species recorded in the Antarctic continent, the Antarctic Peninsula represents an important foraging and breeding area for many species (Figure 42). The great abundance of krill in its adjacent waters represent some of the largest concentrations of this crustacean across the continent, providing vital foraging opportunities to a wide range of species, while ice-free land areas on the Peninsula and adjacent islands, represent essential breeding grounds (Table 11).

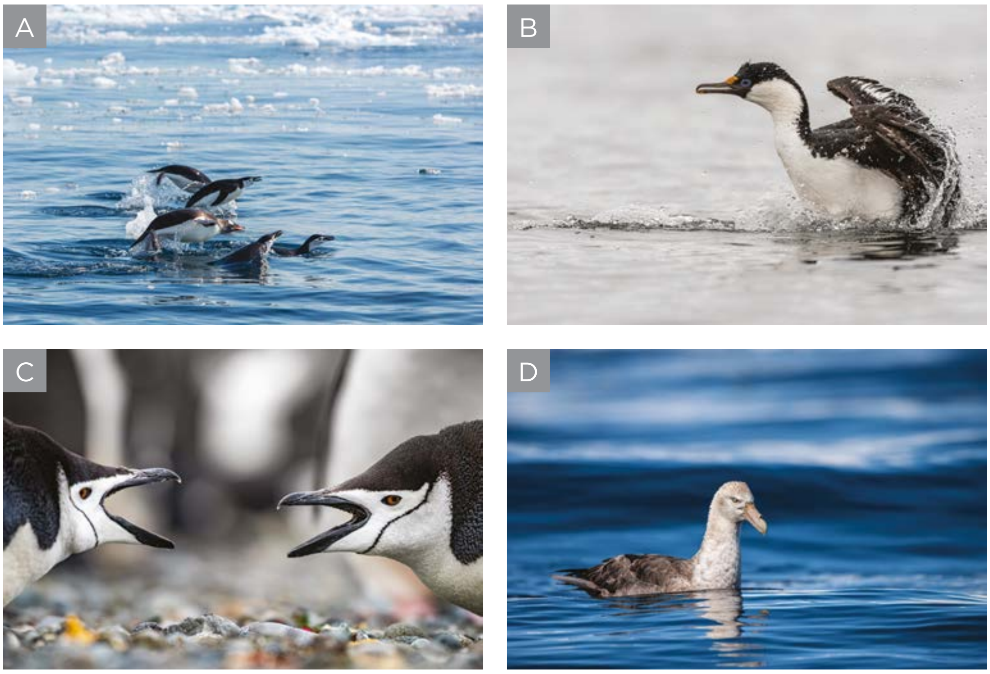


FIGURE 42.

(A) Chinstrap and gentoo penguins swimming among floating ice; (B) Imperial shag; (C) Chinstrap penguins; (D) Southern giant petrel. Jordi Chias/NGS.

Five species of penguins: emperor (*Aptenodytes forsteri*), chinstrap (*Pygoscelis antarcticus*), gentoo (*P. papua*), Adélie (*P. adeliae*) and macaroni penguins (*Eudyptes chrysolophus*) have breeding colonies around the Peninsula and surrounding islands. In recent years, a few pairs of King penguin (*Aptenodytes patagonicus*), a Subantarctic species, have been recorded breeding in different areas of the South Shetland Islands (Juáres et al. 2017, Gryz et al. 2018). There is one breeding colony of emperor penguins in WAP located on Smyley Island, with most emperor breeding occurring in East Antarctica (Fretwell et al. 2014).

Seabirds and marine mammals are important predators of the Antarctic ecosystem. As they forage at sea, they are vulnerable to the potential impact of local activities, such as fisheries, or regional environmental variability. Adélie penguins are decreasing at almost all locations on the Antarctic Peninsula (Cimino et al. 2016) and chinstrap are also declining regionally, with population declines in excess of 50% throughout their breeding range (Trivelpiece et al. 2011, Lynch et al. 2012) (Figure 43). In contrast, gentoo penguins are increasing in abundance and colonies are even expanding southward (Lynch et al. 2012) (Figure 44).

FIGURE 43.

Population trends for Adélie penguin colonies across Antarctica. Source: Cimino et al. 2016.

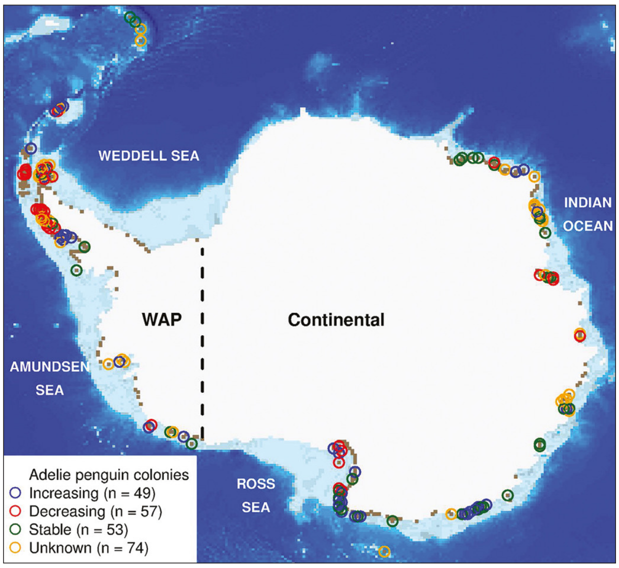


FIGURE 44.

Changes in penguin populations in the Palmer study region, 1974–2010. Source: Bill Fraser, Palmer Station Antarctica LTER.

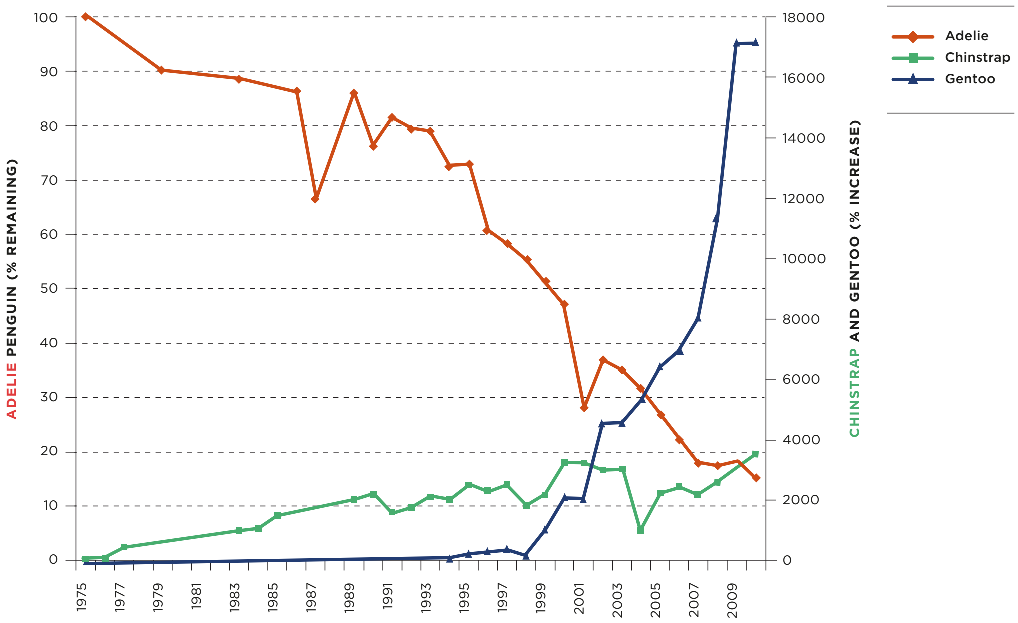


TABLE 11.

Main bird species of Antarctica and associated population thresholds required for Important Bird Area (IBA). Source: Important birds in Antarctica, 2015[1].

Name	Latin name	Red List Status	IBA Criteria	Pop. Threshold (pairs)[2]	Global Population (individuals)	Global Population (pairs)	Source
Emperor Penguin	*Aptenodytes forsteri*	NT	A1, A4ii	2380		238000	Fretwell et al. 2012
Gentoo Penguin	*Pygoscelis papua*	NT	A1	3900		387000	Lynch 2012
Adélie Penguin	*Pygoscelis adeliae*	NT	A1, A4ii	[20000] 37900		[1830000–2880000] 3790000	[Woehler 1993, Woehler and Croxall 1997] Lynch & La Rue 2014
Chinstrap Penguin	*Pygoscelis antarcticus*	LC	A4ii	27000	8000000	~2666667	World Bird Database, BirdLife Int.
Macaroni Penguin	*Eudyptes chrysolophus*	VU	A1	1500		6300000	Crossin et al. 2013
Wilson's Storm-petrel	*Oceanites oceanicus*	LC	A4ii	70000	12–30000000	~4-10000000	Brooke 2004
Black-bellied Storm-petrel	*Fregetta tropica*	LC	A4ii	1600	50000	~160000	Brooke 2004
Light-mantled Albatross	*Phoebetria palpebrata*	NT	A1, A4ii	10 (A1), 200 (A4ii)	87000	~20000	ACAP 2010a
Southern Giant Petrel	*Macronectes giganteus*	LC	A4ii	500		~50000	ACAP 2010b
Southern Fulmar	*Fulmarus glacialoides*	LC	A4ii	10000	1000000	1000000	Creuwels el al. 2007
Antarctic Petrel	*Thalassoica antarctica*	LC	A4ii	30 000	10–20000000	~ 3 - 7000000	Brooke 2004

Cape Petrel	*Daption capense*	LC	A4ii	6700	2000000	~670000	Brooke 2004
Snow Petrel	*Pagodroma nivea*	LC	A4ii	13000	4000000	~1300000	Brooke 2004
Antarctic Prion	*Pachyptila desolata*	LC	A4ii	166000	50000000	~16600000	Brooke 2004
Imperial (Antarctic) Shag	*Phalacrocorax [atriceps] bransfieldensis*	LC	A4i	133	40000	~13333	Waterbirds Population Estimates IV - bransfieldensis treated as a subsp of atriceps
Snowy (Greater) Sheathbill	*Chionis albus*	LC	A4ii	100	10000	10000	Handbook of the Birds of the World
Kelp Gull	*Larus dominicanus*	LC	A4i	140	30–60000	~10–20000	Waterbirds Population Estimates V [Antarctic Peninsula & Atlantic sub-Antarctic Islands]
Antarctic Tern	*Sterna vittata*	LC	A4i	366	110000	~36666	Waterbirds Population Estimates III [S. v. gaini Antarctic Peninsula and S Shetland Islands?]
South Polar Skua	*Catharacta maccormicki*	LC	A4ii	50	10000–19999	~3000–7500	World Bird Database, BirdLife Int.
Brown Skua	*Catharacta antarctica*	LC	A4ii	75	10000–19999	~3000–7500	World Bird Database, BirdLife Int.
Seabirds (including all species of penguin, procellariiform, sheathbill and skua)			A4iii	10000	N/A	N/A	
Waterbirds (including all species of shag, gull and tern)			A4iii	10000	N/A	N/A	

[1] Table 1 has been updated to reflect data published since the IBA assessment was completed for the Antarctic Peninsula (Harris et al. 2011). Where available data were based on estimated number of individuals, in order to account for juveniles in the population, this has been divided by three to give mature pairs.

[2] Population thresholds for each species vary according to which IBA selection criteria is being applied. Table 1 shows the minimum population threshold needed to satisfy one of the IBA criteria for each species, excluding the thresholds required to satisfy criterion A4iii. If criterion A4iii were considered, the threshold for species of chinstrap and Adélie penguin, Snow Petrel, Wilson's Storm-petrel, Antarctic Petrel and Antarctic Prion would fall to 10,000 pairs.

The observed declines have been linked to climate change and the increased competition for krill from baleen whales and pinnipeds as their populations recover from human harvesting, as well as increasing krill fishing (Trivelpiece et al. 2011). For instance, a spatiotemporal overlap between top predators (pygoscelid penguins and fur seals) was observed throughout the Antarctic Peninsula and South Orkney Islands region, including breeding colonies and areas where recent fishing activity has concentrated (Hinke et al. 2017). Also, a spatial overlap between whale presence and concentrated fishing activities in the Gerlache Strait and the Bransfield Strait (Mar de la Flota*) has also been reported (Weinstein et al. 2017). Bearing in mind the future projection of an increase in the krill fishery activities, the protection of krill fishing predators become one key element to be considered in the Domain 1 MPA proposal.

Importantly, a major abundance hotspot of Adélie penguin identified in 2018 at Danger Islands off the northern tip of the Antarctic Peninsula was reported (Borowicz et al. 2018). Moreover, in this region there is another mega colony with 104,000 breeding pairs located at Hope Bay/Esperanza (Santos et al. 2018). The survey conducted by Borowicz and colleagues revealed that Danger Islands host 751,527 breeding pairs of Adélie penguins, more than the rest of the AP region combined, and include the third and fourth largest Adélie penguin colonies in the world. However, the WAP is facing increased environmental variability due to the effects of climate change. Their impact is difficult to assess. For instance, the effect of multiple stressors and their synergistic effects might become significant threats to krill populations in the Southern Ocean (Kawaguchi et al. 2013). Because of the key role that krill plays in the Antarctic ecosystem, negative effects produced by climate change may cascade to the trophic web and hence to the entire ecosystem. Alternatively, these changes will also affect top predators; either by the loss or gain of critical habitat such as the territory used during reproduction and/or by modifying food webs, having a direct impact on birds and mammals feeding habits. Either way, the reduction of the sea ice is likely to affect the reproductive success of ice-dependent species, noting that species that do not depend on sea ice could benefit (Forcada & Trathan 2009, Flores et al. 2012).

2.4. Marine Mammals

There are 21 marine mammal species recorded in the Antarctic, including 6 species of pinnipeds and 15 species of cetaceans (Table 12). Four of the pinnipeds are endemic to the Southern Ocean: the crabeater (*Lobodon carcinophagus*), Weddell (*Leptonychotes weddellii*), Ross (*Ommatophoca rossii*) and leopard seals (*Hydrurga leptonyx*); and are year-round residents of the pack-ice (Figure 45). Crabeater seals are by far the most abundant, with an upper population estimation of 8 million; whereas leopard seals are the least abundant with an estimated abundance of 35,000 individuals (Lowther 2018).

TABLE 12.

Antarctic marine mammal species abundance, trends and conservation status. Source: Lowther 2018.

Taxonomic classification	Common name	Abundance	Trend	Conservation Status
Order Cetacea				
Suborder Odonroceti				
Family Delphinidae				
· ***Lagenorhynchus cruciger***	Hourglass dolphin	144500[a]	Unknown	Least Concern
· ***Orcinus orca***	Killer whale	25000[b]	Unknown	Data Deficient
· ***Globicephala melas***	Long-finned pilot whale	200000[c]	Unknown	Data Deficient
Family Physeteridae				
· ***Physeter macrocephalus***	Sperm whale	360000 (global)	Unknown	Vulnerable
Family Ziphiidae				
· ***Berardius arnuxii***	Arnoux's beaked whale	Unknown	Unknown	Data Deficient
· ***Hyperoodon planifrons***	Southern bottlenose whale	599300[a]	Unknown	Least Concern
· ***Mesoplodon layardii***	Strap-toothed whale	Unknown	Unknown	Data Deficient
Suborder Mysticeti				
Family Balaenidae				
· ***Eubalaena australis***	Southern right whale	7500	Icreasing	Least Concern
Family Balaenopteridae				
· ***Balaenoptera musculus***	Blue whale	1700[d]	Icreasing	Endangered
· ***B. m. brevicauda***	Pygmy blue whale	Unknown	Unknown	Unknown
· ***B. physalus***	Fin whale	1500	Unknown	Endangered
· ***B. borealis***	Sei whale	10,000 (south of 30°S)	Unknown	Endangered
· ***B. acutorostrata subsp***	Dwarf minke whale			
· ***B. bonaerensis***	Antarctic minke whale	339000	Unknown	Data Deficient
· ***Megaptera novaeangliae***	Humpback whale	37000	Increasing	Least Concern
Order Carnivora				
Suborder Pinnipedia				
Family Otariidae				
· ***Arctocephalus gazella***	Antarctic fur seal	5000000	Decreasing	Least Concern
Family Phocidae				
· ***Leptonychotes weddellii***	Weddell seal	633000	Unknown	Least Concern
· ***Ommatophoca rossii***	Ross seal	78500	Unknown	Least Concern
· ***Lobodon carcinophaga***	Crabeater seal	8000000	Unknown	Least Concern
· ***Hydrurga leptonyx***	Leopard seal	35500	Unknown	Least Concern

Unless otherwise stated, numbers are taken from the IUCN Red List. The difficulties inherent with estimating posthunting population trends in Antarctic marine mammals is clearly seen in the number of "Unknown" trends for cetaceans and pinnipeds. [a]Kasamatsu and Joyce (1995). [b]Branch and Butterworth (2001). [c]Waring et al. (2006). [d]Branch et al. (2004).

FIGURE 45.

Leopard seals are among the top predators of Antarctica. Jordi Chias/NGS.

Krill is the major item in the diet of crabeater seals and makes up around half the food eaten by leopard seals. Antarctic fur seals, also wide distributed in the area (*Arctocephalus gazella*) feed extensively on krill but can switch for fish and squid when krill availability decreases (Everson 2000). Most Antarctic pinnipeds (except for fur seals) have capital reproduction, meaning that during gestation they build up fat reserves that they use during the lactation period. In Antarctic pinnipeds the gestation period lasts from summer to summer (Forcada 2008). It is also worth noting that a large influx of male Antarctic fur seals from Subarea 48.3 into Domain 1 occurs in late summer/early autumn. As a potentially large, transient population of krill-dependent predators, accounting for their main foraging areas was an important consideration for the MPA planning process.

Of the 16 cetaceans, 9 species are baleen whales (Mysticeti) and 7 species are toothed whales (Odontoceti), and none are exclusive to Antarctic waters (Costa & Crocker 1996) (Figure 46). Mysticeti whales are highly migratory and are only seasonally abundant in the Southern Ocean during the summer months, whereas in winter they migrate to breed on warmer waters. In Antarctica, whales feed and build up fat deposits to survive their long migration to subtropical and tropical waters where they breed but hardly feed for the remainder of the year (Lockyer & Brown 1981). All seven species of baleen whales that occur south of the Antarctic Polar Front have been extensively hunted. The main species that feed predominantly on krill are the following (Everson 2000): minke whale (*Balaenoptera acutorostrata*), blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), sei whale (Balaenoptera borealis), and humpback whale (*Megaptera novaeangliae*). The southerly limit of their foraging migration is the northern limit of the pack ice zone. Consequently, their foraging range varies as the pack ice retreats (Everson 2000).

Humpback whales (*Megaptera novaeangliae*) have recovered to become the most numerous whale species in the region (Herr et al. 2016). However, three whale species—blue (*B. musculus*), fin (*B. physalus*) and sei (*B. borealis*)—are listed as Endangered on the International Union for the Conservation of Nature Red List as a result of the sharp population declines due to indiscriminate whaling in the 20th century. It is estimated that over 1 million whales were killed, with blue whale numbers reduced to approximately 1% of their pre-harvest abundance (Branch et al. 2004). The use of Antarctic waters during the brief summer feeding season, highlights the importance of these waters for this highly threatened group of species.

FIGURE 46.

Humpback whales visit the Antarctic during summer months. Jordi Chias/NGS.

In Antarctic waters, three different ecotypes of killer whales (Type A, B1, and B2) have been described based on morphology and prey specialization. In the Antarctic Peninsula, it appears to be two size variants of type B killer whales—a large form that wave-washes seals off ice floes (Visser et al. 2008) and takes an occasional Antarctic minke whale, and a smaller form that forages in more open water. The smallest version has been observed in the Gerlache Strait feeding on penguins (Pitman & Ensor 2003).

CHALLENGES TO CONSERVATION

CHALLENGES TO **CONSERVATION**

3.1. Industrial Fishing

Krill fishing has historically been the largest fishery in the Southern Ocean and CCAMLR has successfully managed this fishery using a precautionary approach, while also allowing the recovery of certain fish species that were overexploited in the past (Figure 47). However, the fishery has concentrated its efforts in certain areas in more recent years (e.g., Bransfield Strait [Mar de la Flota*]). Changes in the dynamics of the krill fishery (e.g., technology, economics, species distribution patterns), along with current and projected changes in the marine environment around the Antarctic Peninsula, are challenging the way the krill fishery is managed.

FIGURE 47.

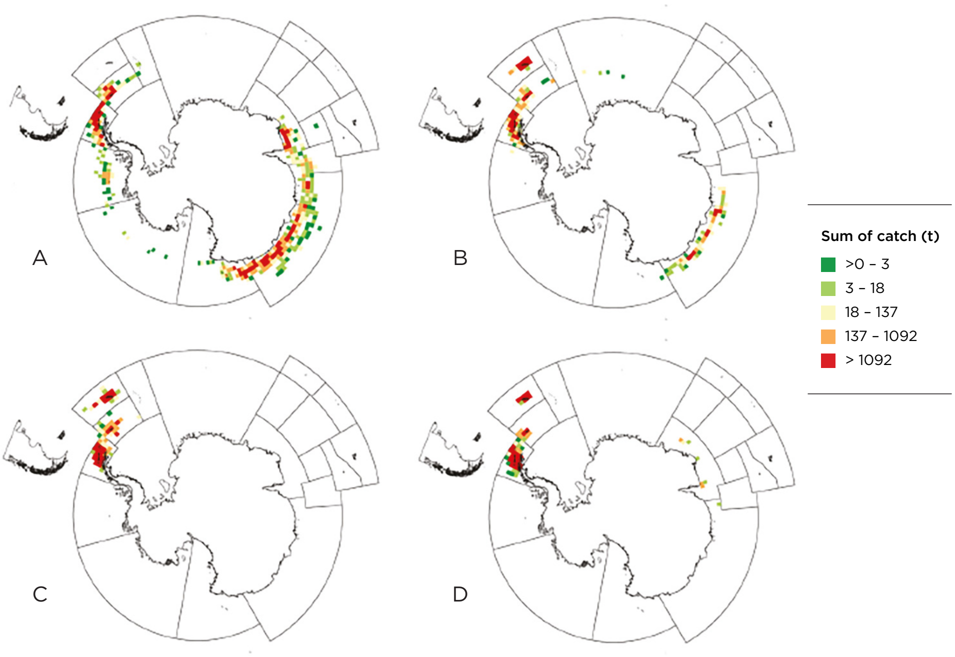
Antarctic krill represents the main fishery around Antarctica. Jordi Chias/NGS.

The continuous fishing system (i.e. a system where the cod-end of the net is emptied via a pump connected to the vessel rather than being hauled aboard as in 'traditional' trawling) was first used in the krill fishery in 2004 by a Vanuatu-flagged vessel.

This vessel also fished in 2005, then replaced by a Norwegian-flagged vessel, also using the continuous fishing system. As the fishery has developed, the location of fishing has moved from the Indian Ocean to the Atlantic Ocean sector and has focused almost entirely in the Atlantic sector since the early 1990s. In the past 10 years, the spatial distribution of the fishery has become focused in the region of the Bransfield Strait (Mar de la Flota*) off the Antarctic Peninsula (Subarea 48.1), to the northwest of Coronation Island (Subarea 48.2) and to the north of Subarea 48.3 (Figure 48).

FIGURE 48.

Spatial distribution of catches in the krill fishery reported to CCAMLR aggregated by 1° latitude by 2° longitude cells for (A) 1980 to 1989, (B) 1990 to 1999, (C) 2000 to 2009, and (D) 2010 to 2018. Source: CCAMLR Krill fishery report 2018.



Patagonian toothfish (*Dissostichus eleginoides*) and Antarctic toothfish (*D. mawsoni*) are targeted by authorized fisheries in the Southern Ocean, using mainly bottom-set longlines in depths of 1,200–1,800 m. These highly prized fishes have also caught the attention of illegal, unreported, and unregulated fishing vessels in the Southern Ocean. Commercial fishing for toothfish species is currently not happening in the Antarctic Peninsula area. On the contrary, mackerel icefish (*Champsocephalus gunnari*) was heavily exploited in the 1970s and 1980s in this area and concerns over the levels of exploitation, and the high annual variability in catches, led to the closure of the fisheries in the early 1990s. This fishery is now targeted using midwater trawls in CCAMLR subarea 48.3, and bottom and midwater trawls at Heard and McDonald Islands. The fishery may only occur within two years of a stock assessment, if sufficient stock is determined to be available.

Although catch limits exist for krill in the Antarctic Peninsula/Scotia Sea region, where the fishery currently operates (Figure 49), these limits are set for large areas of the ocean, and do not take into account the smaller scale interactions between the fishery, krill, and krill predators. Virtually all the krill catch is concentrated close to known breeding colonies of land-based krill predators. It is very difficult to quantify the feeding needs of krill-dependent predators in those areas where overlap between the fishery and krill predators occurs. The fishery directly competes with krill predators such as penguins and whales and may adversely affect these sensitive species (Trathan et al. 2018). The combined impact of climate change and krill fishing poses an additional challenge for ecosystem-based management of the krill fishery.

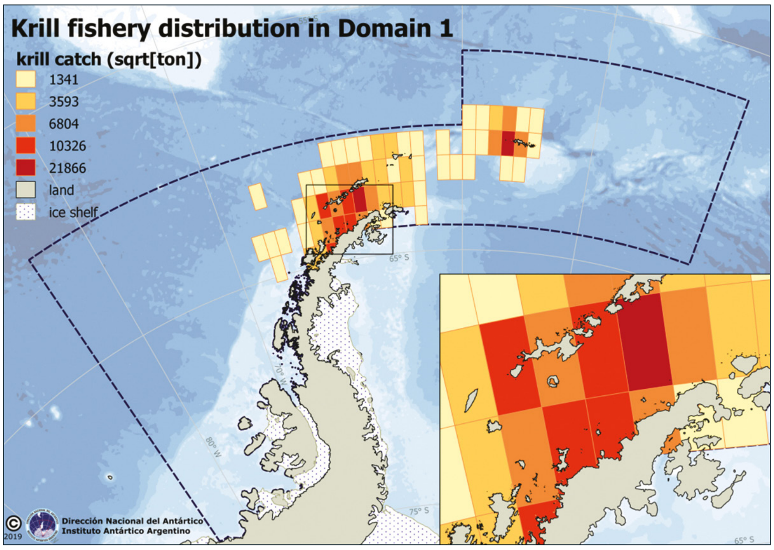


FIGURE 49.

Distribution of krill fishery catches for the 2006–2015 fishing seasons in Domain 1. Data plotted in accordance with the Rules for Access and Use of CCAMLR data. Note the high concentration of catches in few places, including the Bransfield Strait (Mar de la Flota*) and the west of Coronation Island in the South Orkney Islands.

The use of new technologies to fish and process krill is changing the economics of the fishery and represents new management challenges. Although some important progress has been made regarding the management of the krill fishery, CCAMLR is still facing important challenges that need to be addressed in a strategic manner to ensure that the Antarctic krill fishery develops in response to management rather than the reverse (Gascón & Werner 2009).

In addition to the need to develop krill catch limits at smaller geographical scales, CCAMLR has also acknowledged that an improved management regime for krill fisheries should include the development of a feedback management procedure. Under this feedback approach, management measures are continuously adjusted in response to relevant information. Such a management scheme for krill, which needs to account for interactions between the fishery, krill predator populations, and environmental factors, is currently the center of attention of the CCAMLR Scientific Committee. In order to advance the development options for the krill fishery, a workshop on Krill-fishery Management for Subareas 48.1 and 48.2 took place in June 2019, in Concarneau, France with a wide participation of scientists, members of the fishing industry and environmental organizations from Argentina, Australia, Chile, France, Germany, Korea, Norway, Ukraine, the UK, and the USA.

3.2. Climate Change

The Western Antarctic Peninsula has warmed significantly over recent decades and is considered among the fastest warming regions on Earth (Turner & Overland 2009, Thomas et al. 2013) (Figure 50). The strong warming trends observed in this region are not only restricted to the atmosphere, but also a warming of the summer ocean surface has also been detected (Meredith & King 2005). In fact, the seawater temperatures in some coastal areas of the WAP has already reached the predicted temperatures for 2100 (Cárdenas et al. 2018). This warming has influences on the cryosphere, including ice-shelf collapses and a decrease in the extent and seasonality of sea-ice. Furthermore, the majority of the glaciers over WAP have retreated during the last 60 yr (Cook et al. 2014). An important consequence of the glacial retreat is causing massive discharge of sediment-laden melt water (Vaughan et al. 2006). This discharge not only affects the hydrographical characteristics of the water column but also impact on the physiology of aquatic organisms (Torre et al. 2012, Fuentes et al. 2016). In fact, this particle discharge is currently recognized as a driver for changes at community-assemblage level, with long-term effects on the biomass and species composition (Sahade et al. 2015).

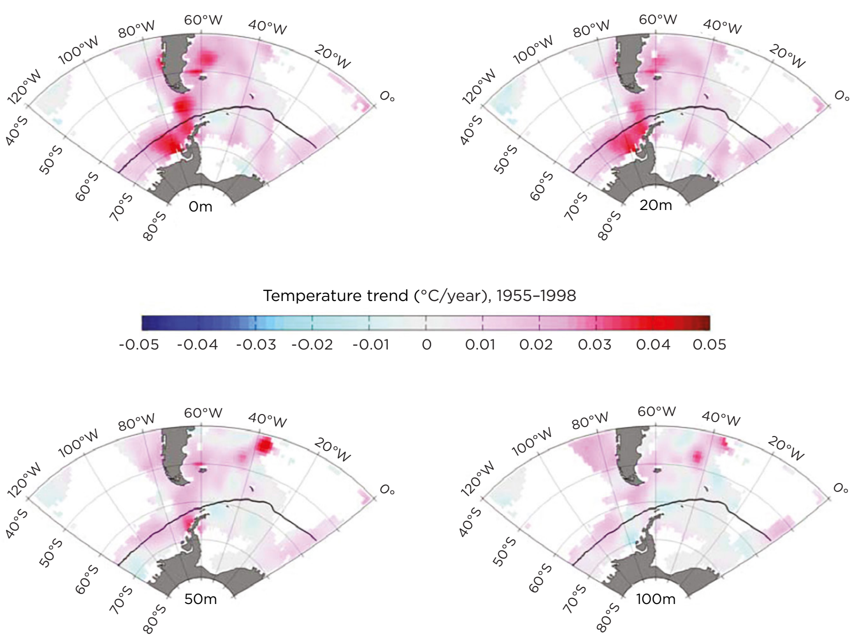


FIGURE 50.

Trends in ocean summer temperatures during 1955–1998 at four different depths. Source: Meredith & King 2005.

Climate change is a major threat to the long-term survival of Antarctic marine communities. Since Antarctic organisms have evolved in this very cold and stable environment, most species are expected to show limited capacity to adapt to even slight increases in seawater temperature (Peck et al. 2010). Laboratory experiments have assessed the capacity of Antarctic organisms to cope with thermal stress, with some cases in which increases in 2–3° C above the normal can produce significant changes in organisms such as not having the capacity to perform essential functions (Peck et al. 2004, Ingels et al. 2012). Experimental studies have shown that small increases in seawater temperature of 1°C can also produce effects at the community level, reducing the diversity and interactions between species (Ashton et al. 2017). The projected seafloor warming is expected to produce a reduction in suitable habitats and significant shifts in the distribution of organisms depending on whether they respond positively or negatively to warming (Griffiths et al. 2017).

In addition, extended glacier retreat is among the main consequences of the rapid warming of the WAP (Figure 51). The rapid warming along the WAP and extended glacier retreat in Antarctica are causing environmental shifts with the potential to severely affect benthic coastal ecosystems (Lagger et al. 2017). The reduction of ice is expected to increase the effect of icebergs on seabed communities as with the increased in glacier retreat, more icebergs will circulate in open water producing disturbance by removing benthic organisms (Barnes 2017). The loss of ice coverage is also opening new ice-free areas for biological productivity and benthic colonization (Peck et al. 2010, Lagger et al. 2017). The present warming climate has the potential to cause substantial expansion of these ice-free areas across Antarctica, possibly modifying the current distributions of Antarctic biota (Lee et al. 2017). Glacier fronts retreated at an unprecedented speed, increasing around 44% the ice-free coast between 1956–2008 (Rückamp et al. 2011). Considering that the estimated area affected by changes in the extension of tidewater glaciers is around 2.97×106 km^2 (Gutt et al. 2015), evaluation of climate change impacts on Antarctic ecosystems is very necessary.

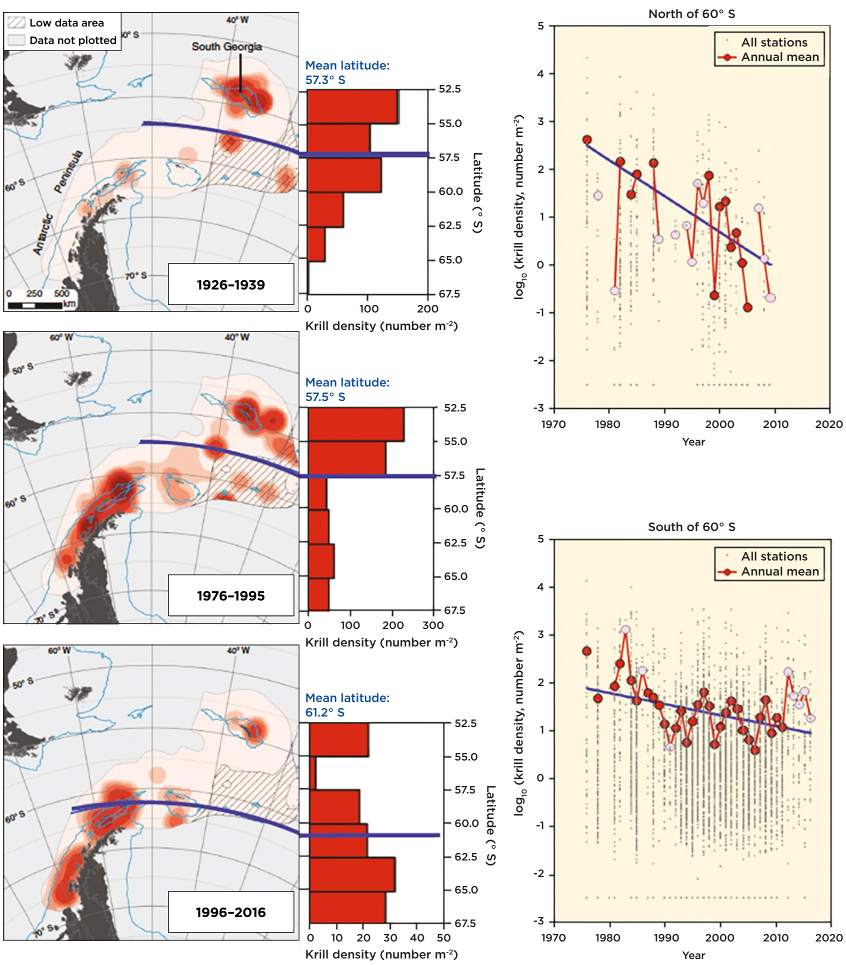
FIGURE 51.

Accumulated mass change (in gigatons) of Antarctic snow. Source: NASA's Scientific Visualization Studio.

The rapid warming of high-latitude ecosystems can also have major implications for fisheries, including the krill fishery of the Southern Ocean. A recent study has shown that the distribution of krill has contracted southward during the past 90 years (Figure 52). This changing distribution is already altering Antarctic food webs that heavily rely on krill and could have an impact on biogeochemical cycling (Atkinson et al. 2019).

FIGURE 52.

Southward contraction of krill distribution within the Southwest Atlantic sector. Source: Atkinson et al. 2019.



4.1. Tourism

People have been visiting Antarctica through organized tours for over 60 years. Tourism is managed through the Antarctic Treaty System and it accounts for the largest number of people visiting the region every year, between October and April. The main rules and guidelines for visitors and operators of tourist expeditions arise from the Antarctic Treaty Consultative Meetings (ATCM), including those established within the Protocol on Environmental Protection and its associated resolutions, in order to ensure these activities do not produce adverse impacts on the Antarctic environment or on its scientific and aesthetic values. Nearly all visitors to the Antarctic do so under the auspices of the International Association of Antarctica Tour Operators (IAATO), which also participates in the ATCM as an invited expert organization. IAATO is an international member association, comprising over 100 companies and organizations from all over the world, which support IAATO's mission to advocate and promote safe and environmentally responsible private-sector travel to the Antarctic. IAATO operators organize and conduct expeditions to Antarctica, planning their activities to have no more than a minor or transitory impact on the environment in accordance with the Antarctic Treaty System (ATS) Environmental Protocol. The work of IAATO is facilitated by a Secretariat and supported by eight thematic committees and six working groups covering field operations, marine and environmental issues, compliance and dispute resolution, plastic elimination, climate change, external stakeholder engagement, tourism growth, education and outreach. IAATO meets at least once a year, during which policies, procedures, challenges and tasks are agreed (Lynnes 2019).

Tourism to Antarctic coastal areas began in the late 1950s and early 1960s with one or two chartered ships carrying a few hundred passengers along with a handful of yachtsmen (Lynnes 2019). Deep field operations, activities that take place in the interior of the continent, commenced in 1985. These expeditions were initially to support climbers tackling Mt Vinson, Antarctica's highest mountain, and subsequently to fly the first group of tourists to the South Pole in 1987–88 season. Ever since, Antarctic tourism has been growing to include thousands of seaborne passengers arriving yearly on dozens of vessels while several hundred others fly deep into the continent (Figure 53). Most ship borne expeditions to Antarctica occur in the waters along the western side of the Antarctic Peninsula, with landings occurring in specific sites authorized by the Antarctic Treaty.

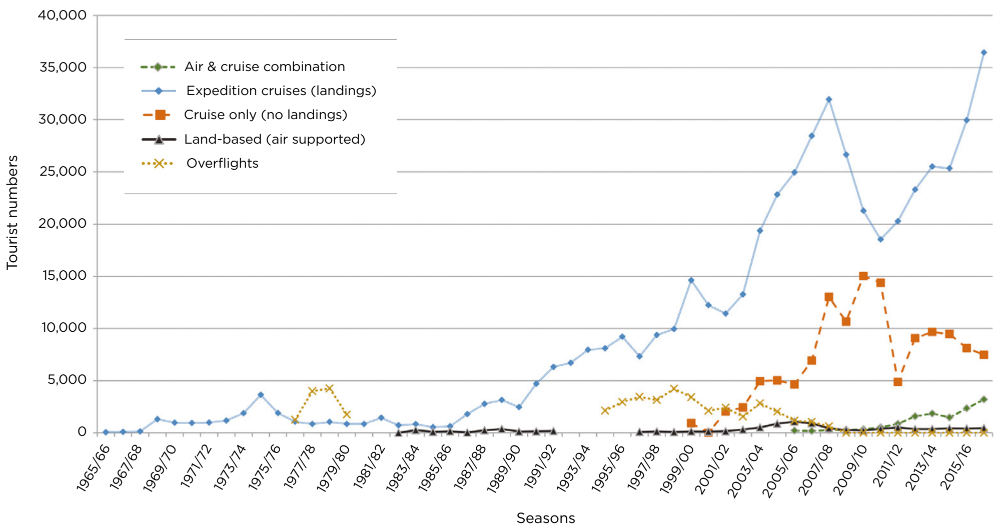


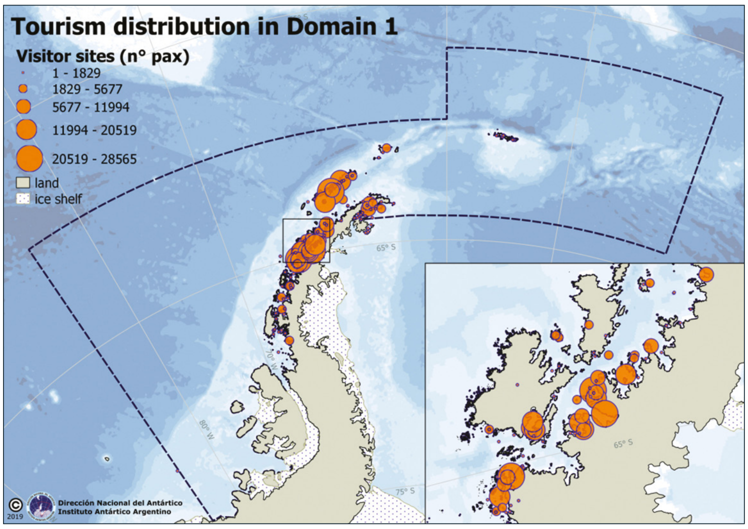
FIGURE 53.

Tourist numbers visiting Antarctica during the period 1989–2017. Source: IAATO, 2017.

During the 2018–19 Antarctic season, the total number of visitors traveling with IAATO Operators was 56,168, representing an increase of 8.6% compared to the previous season. This figure represents a new high, having passed the previous peak of the 2017–18 season (51,707) (IAATO 2019) (Figure 54). In this regard, the Antarctic Treaty System is looking carefully at the possible impacts the growth and certain tendencies in Antarctic tourism may have in the region (Lynnes 2019).

FIGURE 54.

Tourism distribution for the 2017–2018 season based on IAATO statistics. Note that few sites concentrate the higher number of visitors especially in the Gerlache Strait and South Shetland Islands.



4.2. Invasive Species

Global warming is now removing the physiological barriers that have isolated Antarctica from lower latitudes. Recent evidence has demonstrated that the Antarctic Circumpolar Current is more permeable than previously thought, as there is now evidence of the presence of Subantarctic seaweeds in the Antarctic Peninsula, that were able to drift and pass this physical barrier through small scale currents and transport produced by storms (Fraser et al. 2018). In addition, changes in seawater temperature will also produce significant changes not only in the reduction in suitable habitats for Antarctic organisms (Griffiths et al. 2017), but also by creating suitable conditions for other organisms that were not able to colonize Antarctic waters for millions of years. King crabs are a good example of the changes that are already occurring in the Southern Ocean.

As sea temperatures continue to rise (Figure 55), the invasion of durophagous predators (i.e., animals that consume hard-shelled prey such as bivalves, gastropods, and large crustaceans, typically by crushing the mineralized exoskeleton), will modernize the shelf benthos and erode the indigenous character of marine life in

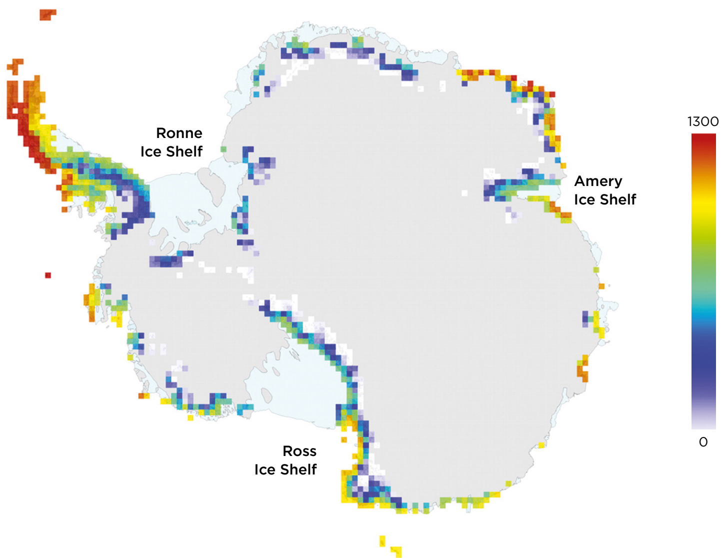
Antarctica, that has developed without durophagous for millions of years. In 2007, a population of stone crab (Lithodidae) was encountered on the continental slope of Antarctica in the Bellingshausen Sea between 1,123 and 1,304 m water depths (Thatje et al. 2008). The increased records of lithodid crabs in deeper waters and on seamounts surrounding the Antarctic continent in recent years raised the question of established lithodid crab populations in the Southern Ocean. Recent studies have recorded reproductively viable populations of king crabs at 841- to 2,266-m depth off the continental shelf of the WAP (Aronson et al. 2015), having the potential to successfully reproduce and establish other populations in shallower zones in the future (Smith et al. 2017). Warming is likely to remove physiological barriers on lithodid crabs that are currently unable to invade the shallow waters of the high Antarctic (Aronson et al. 2007). Currently, seawater temperature in the area above 500 m depth constitutes a barrier to stop these crabs from migrating to shallower areas, however further warming is likely to remove this cold-water barrier in a few decades (Aronson et al. 2015).

This "invasion hypothesis" suggests that decapod crabs were driven out of Antarctica 40–15 million years ago and are only now returning as "warm" enough habitats become available. However, distribution patterns, species richness, and levels of endemism all suggest that, rather than becoming extinct and recently re-invading from outside Antarctica, the lithodid crabs have likely persisted, and even radiated, on or near to the Antarctic slope (Griffiths et al. 2013).

In any case, predictive scenarios suggest that king crabs have the potential to expand their distribution having dramatic consequences for Antarctic benthic communities. This along with the new evidence of a "permeable" Antarctic Circumpolar Current will transform a previously hostile habitat for many non-Antarctic species into a habitat with more suitable condition for species that were absent for millions of years from the fragile Antarctic marine ecosystem.

FIGURE 55.

Increase in annual cumulative degree days under future global warming scenarios (SRES Scenario A1B) indicating risk of alien species establishment. Source: Chown et al. 2012.



CONSERVATION OPPORTUNITIES

CONSERVATION **OPPORTUNITIES**

A number of small Antarctic Specially Protected Areas (ASPAs) are already scattered throughout Domain 1, including the South Shetland Islands and the Palmer Archipelago. But these small areas (generally terrestrial with a small marine component), managed by the Antarctic Treaty Consultative Meeting, are inadequate to protect the Peninsula's krill populations, millions of breeding seabirds, marine mammals, and the greater ecosystem (Werner & Bransome 2017).

The process to designate an additional MPAs in the Antarctic Peninsula and the South Scotia Arc (referred by CCAMLR as Domain 1) has been led by Argentina and Chile and started in 2012. Since then, more than 150 spatial layers of scientific data were created in a collaborative process involving many CCAMLR members. These layers describe the spatial distribution of ecosystem processes, habitats and key species, and contain data on human activities such as fishing, tourism, scientific, and logistic activities (CCAMLR 2016).

Argentina and Chile have organized several international meetings focused on Domain 1 to facilitate the collation, analysis, discussion and integration of data by interested CCAMLR Members. In 2012, the First International Workshop on Domain 1 MPA, held in Valparaíso, Chile, defined the conservation objectives for the area (CCAMLR 2012). In 2013, Argentina and Chile held a binational workshop in La Serena, Chile, where the two countries defined the necessary steps towards creating the MPA proposal and agreed to use the MARXAN program as the systematic conservation planning tool (CCAMLR 2013). In 2015, Argentina organized the Second International Workshop on D1MPA, held in Buenos Aires. This meeting was fundamental in laying the scientific and technical foundations for each conservation objective. Also, in the 2015 meeting, data layers were updated, new data sets were added, and a range of specific conservation target levels were defined for analysis (CCAMLR 2015, Werner & Bransome 2017). In 2016, an informal workshop held in Bologna, Italy, allowed the proponents to present concrete results including diverse MARXAN scenarios based on different conservation target levels and cost layers; also incorporating complementary work done by other CCAMLR Members in support of the protection in Domain 1.

In July 2017, Argentina and Chile presented a preliminary proposal for a D1MPA at the meeting of the CCAMLR Working Group on Ecosystem Monitoring and Management in Buenos Aires in July and at the CCAMLR annual meeting in October (CCAMLR 2018) for Members' consideration. It included the identification of the Priority Areas for Conservation (Figure 56) and a preliminary MPA model, that protects key conservation objectives, agreed by the CCAMLR scientific community, such as representative benthic and pelagic habitats and ecosystem processes, including high productivity features; and important areas for the life cycles of zooplankton, fishes, birds and mammals (Figure 57).

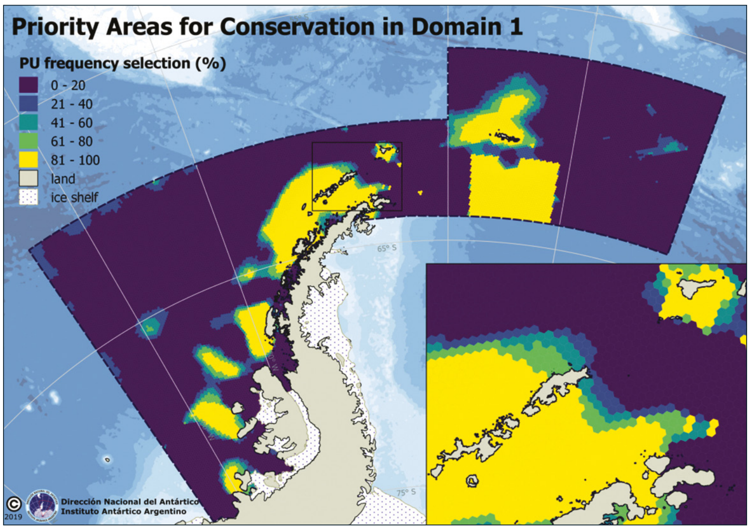


FIGURE 56.

Priority Areas for Conservation (PAC) for Domain 1 based on the protection of representative examples of benthic and pelagic habitats and processes, and important areas for life cycles of zooplankton, fishes, birds and mammals.

In addition, during the same year, the creation of a D1MPA Expert Group was proposed by the proponents and agreed by the Commission given the natural complexity and diversity of human activities in the region, with the aim of increasing transparency and facilitate coordination and communication amongst interested stakeholders.

Finally, in 2018, Chile and Argentina presented a joint formal proposal for the creation of a Domain 1 Marine Protected Area (D1MPA) to the CCAMLR Commission and Scientific Committee (CCAMLR 2018), that took into account not only the conservation of key natural values but also sustainable fishing activities in the region. The proposal received great support from many CCAMLR Members. The entire process towards the development of the D1MPA was characterized from the beginning as open, transparent and inclusive, incorporating suggestions and concerns of the diverse stakeholders aimed to facilitate consensus.

The D1MPA protects biodiversity hotspots as well as representative and unique benthic and pelagic habitats. It includes no-fishing zones in some coastal areas that are important foraging grounds for birds and mammals, including penguins and whales, and of relevance for krill and fish during some stages of their life cycles, predominantly

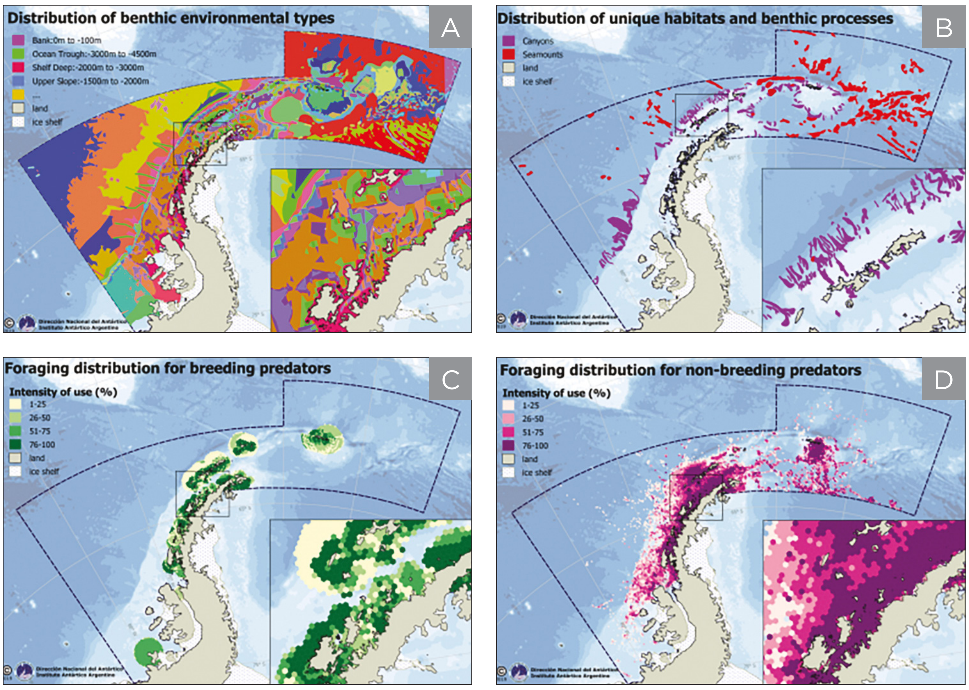


FIGURE 57.

Distribution of key natural values in Domain 1 as an example of the protection granted by D1MPA. (A) representative examples of benthic habitats; (B) distribution of high productivity features including seamounts and canyons; (C) foraging distribution of central place foragers (penguins and fur seals) during breeding; (D) foraging distribution of predators (penguins, pinnipeds and cetaceans) during non-breeding.

For data sources, please see the Methods section.

in the Bransfield (Mar de la Flota*) and Gerlache Straits. Particularly, in these two areas where krill fishing activities have increased in recent years, predator populations are seeing major changes. D1MPA also protects sensitive spawning and nursery habitat for krill and for other commercially and ecologically valuable fish species (i.e. icefish, silverfish, and toothfish), as well as key breeding, foraging, and migration areas for seabirds and marine mammals. It also includes zones for scientific studies on climate change, and zones where sustainable krill fishing is allowed, aimed at avoiding the concentration of the fishery in key areas (CCAMLR 2018).

In the designation of the D1MPA, the development of feedback management for the krill fishery will need to be considered to harmonize both processes. Thus, CCAMLR will need to protect important predator foraging areas in Domain 1, while progressing the feedback management of the krill fishery. One of the objectives of the recent workshop on Krill-fishery Management for Subareas 48.1 and 48.2 that took place in June 2019, in Concarneau, France was to explore how management strategies for the krill fishery, including those within the proposed D1MPA can be integrated and harmonized. The workshop provided an interesting opportunity to discuss how the D1MPA and a management strategy for the krill fishery could be developed in parallel. Based on several conversations that occurred since the proposal was presented last year, some changes to the D1MPA model might be underway. How the spatial conservation objectives of the Convention will interact with the management of the krill fishery in the Antarctic Peninsula area, one of the most impacted and fastest changing regions of the Antarctic, remains one of the ultimate challenges for CCAMLR.

ACKNOWLEDGEMENTS

We would like to express our deep gratitude and acknowledgement to the Chilean Navy (Armada de Chile) for making this expedition possible, particularly to Admiral Julio Leiva, Commander in Chief of the Navy, Rear Admiral Andrés Rodrigo, Rear Admiral Ronald Baasch and the Third Naval Zone Corps, Rear Admiral Fernando Cabrera, Lars Christiansen, Chief of Antarctic Affairs of the Navy. A special thanks goes out to Captain Ivan Stenger and the crew of the Chilean Navy vessel OPV-83 Marinero Fuentealba for their efforts above and below the call of duty during the expedition. Thank you to the Ministry of Foreign Affairs and the Ministry of Defense of Chile, the Director of Antarctica of the Chilean Ministry of Foreign Affairs, Camilo Sanhueza and his staff, Dr Marcelo Leppe, Director of Instituto Antártico Chileno, Dirección General de Aeronáutica Civil, and Secretaria Regional Ministerial de Medio Ambiente de Magallanes. We thank the Ministry of Foreign Affairs and Worship of Argentina, and its dependent Argentine National Antarctic Directorate and the Argentine Antarctic Institute: led respectively by Minister Fernanda Millicay and Director Rodolfo Sánchez; and to the National Director of Antarctic Foreign Policy, Minister Máximo Gowland, for their support during this expedition. Special thanks go to all scientific and logistic personnel at the Argentine stations Carlini and Brown, in particular, the Station Chiefs Army Major Mariano Pintos and Lic. Astrid Zaffiro, and Science Chief Dr Lucas Ruberto for their warm welcome, resource provisions, and cooperation with the team during our short stays at these stations. Thanks also go out to the personnel of the Chilean base Arturo Prat for their hospitality, especially the Commander of Base Prat, Captain of Corvette OM Mr. Engelbert Mori Larenas. Rodolfo Werner was supported by The Pew Charitable Trusts and the Antarctic and Southern Ocean Coalition and is particularly thankful to Claire Christian, Andrea Kavanagh, and Ryan Dolan.

METHODS

A total of 132 dives (87.3 hrs. bottom time) were conducted during the expedition.

Benthic Surveys

Characterization of the benthos was conducted by scuba divers along one 25-m long transects at each sampling location. Transects were run parallel to the shoreline, with depths ranging from 8–27 m, depending on the location of the macroalgae beds or other features. One diver took photographs along the transect line with an underwater camera with an aluminum ruler (10 cm) attached to the housing and used to quantify the sampled area. A total of 25 photographs were taken along the fixed transect at each sampled location to quantify sessile and mobile invertebrates, resulting in a sampled area of ~132 m^2. The resolution of images was sufficiently fine to detect and identify organisms as small as ~10 mm in diameter. A second diver counted sessile invertebrates and macroalgae using a point intercept method at every 20 cm along the transect line.

All animals in each photograph were counted and the total number divided by the area sampled to estimate densities. All discernible fauna were identified to the lowest possible taxonomic level, which was generally species (although bryozoans and some sponges could not always be identified to this level). Some components of the biota were excluded from the analysis: encrusting taxa (some smaller bryozoans and terebellid polychaetes) could not be accurately identified and quantified.

Underwater Fish Surveys

At each survey site, a scuba diver counted and sized all fishes within 1-m of either side of a 25 m transect line (50 m^2). Total fish lengths will be estimated to the nearest cm. All divers noted and/or photographed all fish species observed during the dive.

Deep Drop-camera Surveys

National Geographic's Deep Ocean Mini Dropcams are high definition cameras in a 33-cm diameter borosilicate glass sphere that are rated to ~7,000 m depth (Turchik *et al.*, 2015). This Dropcam Mini contains a Sony Handycam FDR-AX33 4K Ultra-High Definition video with a 20.6 megapixel still image capability. Viewing area per frame for the cameras is between 2–6 m^2, depending on the steepness of the slope where the Dropcam lands. Cameras will be baited with ~ 1 kg of frozen fish and deployed for 6 to 9 hrs. The cameras remained sealed during the entire expedition with data communications performed through a penetrating electrical connector. Lighting at depth was achieved through a high-intensity LED array. Depth gauging was accomplished using an internal logging pressure sensor. The Dropcams were weighted with a 12-kg locally procured sandbag weight with a descent rate of ~1m s-1. The primary weight release mechanism is a burn wire that was activated using onboard battery voltage. The Dropcams are positively buoyant resulting in an ascent rate of ~1 m s-1. Dropcams have an onboard VHF transmitter that allows for recovery using locating antennae with backup location achieved via communication with the ARGOS satellite global tracking system. Dropcams were deployed daily at bathymetric features of interest.

The relative abundance of each species will be calculated as the maximum number of individuals per frame (MaxN). The substrata for each Dropcam deployment will be classified into standard geological categories following Tissot et al. (2007): mud (M), sand (S), pebble (P), cobble (C), boulder (B), continuous flat rock (F), diagonal rock ridge (R), and vertical rock-pinnacle top (T). Seafloor type was defined by a two-letter code representing the approximate percent cover of the two most prevalent substrata in a habitat patch. The first character represented the substratum that accounted for at least 50% of the patch, and the second represented the second most prevalent substratum accounting for at least 30% of the patch.

Data Sources for Figure 57

Panel A. Benthic bioregionalization, extracted from Douglass et al. 2011 (WS-MPA-11/23) and Douglass et al. 2014

Panel B. Canyons and seamounts, extracted from Huang et al. 2014 and Harris et al. 2014.

Panel C. Foraging data for predators during breeding as in Table 13.

TABLE 13.

Foraging data for predators during non breeding. SSI: South Shetland Islands; AP: Antarctic Península; SOI: South Orkney Islands.

Specie	Colony	Data source
Adelie penguins	Copacabana (SSI)	U.S. AMLR Program (1)
	Hope Bay (AP)	Instituto Antártico Argentino (1)
	Signy Island (SOI)	British Antarctic Survey (2)
Chisntrap penguins	Copacabana and Cape Shirreff (SSI)	U.S. AMLR Program (1)
	Signy Island (SOI)	British Antarctic Survey (2)
Gentoo penguins	Copacabana and Cape Shirreff (SSI)	U.S. AMLR Program (1)
	South Orkney Islands	British Antarctic Survey (2)
Emperor penguins	Snow Hill and Smyley Is. (AP)	(3)
Fur seals	Cape Shirreff	U.S. AMLR Program (1)

(1) Unpublished.
(2) Extracted from Trathan et al. 2002.
(3) Extracted from Kirwood & Robertson 1997, Wienecke et al. 1997 and Ratcliffe & Trathan 2001.

Panel D. Foraging data for predators during non breeding, as in Table 14.

TABLE 14.

Foraging data for predators during non breeding. SSI: South Shetland Islands; AP: Antarctic Península; SOI: South Orkney Islands.

Specie	Colony	Data source
Adelie penguins	Aldmiralty Bay (SSI)	U.S. AMLR Program (1)
	Hope Bay (AP)	Instituto Antártico Argentino
	South Orkney Islands	British Antarctic Survey
Chisntrap penguins	Cape Shirreff and Aldmiralty Bay (SSI)	U.S. AMLR Program (1)
	South Orkney Islands	British Antarctic Survey
Gentoo penguins	Cape Shirreff and Aldmiralty Bay (SSI)	U.S. AMLR Program (1)
Fur seals	Cape Shirreff (SSI)	U.S. AMLR Program (1)
Weddell seals	Cape Shirreff (SSI)	U.S. AMLR Program (1)
Leopard seals	Cape Shirreff (SSI)	U.S. AMLR Program (1)
Elephant seals	Cape Shirreff (SSI)	UCSC/U.S. AMLR Program (3)
	Potter Península (SSI)	Alfred Wegener Institute –Instituto Antártico Argentino (4)
Humpback whales	West Antarctic Peninsula	U.S. AMLR Program (2)
Minke whales	West Antarctic Peninsula	U.S. AMLR Program (2)
Killer whales, types A, B1 and B2	West Antarctic Peninsula	U.S. AMLR Program (2)

(1) Extracted from Hinke et al. 2012 y 2017.
(2) Unpublished, coordinated by Bob Pitman, U.S. AMLR Program.
(3) Unpublished, provided by Dan Costa, University of California, Santa Cruz.
(4) Provided by Horst Bornemann (Alfred Wegener Institute), available at PANGAEA and published in De bruyn et al. 2014.

de Bruyn PJN, Reisinger RR, Bester MN, Tosh CA, Carlini AR, Platz J, Bornemann H. (2014). At surface behaviour at location on spot of southern elephant seal from King George Island. doi:10.1594/PANGAEA.749698

Douglass LL, Turner J, Grantham HS, Kaiser S, Constable A, Nicoll R, Raymond B, Post A, Brandt A, Beaver D (2011) A hierarchical classification of benthic biodiversity and assessment of protected areas in the Southern Ocean. Submitted to the CCAMLR Marine Protected Area workshop held in Brest, France in 2011. WS-MPA-11/23.

Douglass LL, Turner J, Grantham HS, Kaiser S, Constable A, et al. (2014) A Hierarchical Classification of Benthic Biodiversity and Assessment of Protected Areas in the Southern Ocean. *PLoS ONE* 9(7): e100551. doi:10.1371/journal.pone.0100551

Harris PT, Macmillan-Lawler M, Rupp J, Baker EK (2014) Geomorphology of the Oceans. *Marine Geology* 352: 4–24.

Hinke J, Watters G, Trivelpiece W, Goebel M. (2012). Synopsis of data from satellite telemetry of foraging trips and migration routes of penguins and pinnipeds from the South Shetland Islands, 1997/98 to present. WG-EMM-12/37.

Hinke JT, Cossio AM, Goebel ME, Reiss CS, Trivelpiece WZ, Watters GM. (2017). Identifying Risk: Concurrent Overlap of the Antarctic Krill Fishery with Krill-Dependent Predators in the Scotia Sea. PLoS ONE 12(1): e0170132. doi:10.1371/ journal.pone.0170132

Huang Z, Nichol SL, Harris PT, Caley MJ (2014) Classification of submarine canyons of the Australian continental margin. *Marine Geology* 357: 362–383.

Kirkwood R and G Robertson (1997). The foraging ecology of female emperor penguins in winter. Ecological Monographs 67, 155-176. doi: 10.2307/2963511

Ratcliffe N and Trathan P. (2011). A review of the diet and at-sea distribution of penguins breeding within the CAMLR Convention Area. CCAMLR Science, Vol. 18: 75-114

Trathan PN, Tanton JL, Lynnes AS, Jessopp MJ, Peat H, Reid K and JP Croxall. (2002). Spatial and temporal variability in foraging patterns of krill predators at Signy Island and South Georgia. WG-EMM-02/33.

Wienecke BC and Robertson G. (1997). Foraging space of emperor penguins Aptenodytes forsteri in Antarctic shelf waters in winter. Marine Ecology Progress Series, 159, 249-263

REFERENCES

Arntz WE, Gutt J, Klages M (1997) Antarctic marine biodiversity: an overview. Antarctic communities: species, structure and survival Cambridge University Press, Cambridge:3–14.

Aronson RB, Smith KE, Vos SC, McClintock JB, Amsler MO, Moksnes P-O, Ellis DS, Kaeli J, Singh H, Bailey JW (2015) No barrier to emergence of bathyal king crabs on the Antarctic shelf. Proceedings of the National Academy of Sciences 112:12997–13002.

Aronson RB, Thatje S, Clarke A, Peck LS, Blake DB, Wilga CD, Seibel BA (2007) Climate change and invasibility of the Antarctic benthos. Annu Rev Ecol Evol Syst 38:129–154.

Ashjian CJ, Rosenwaks GA, Wiebe PH, Davis CS, Gallager SM, Copley NJ, Lawson GL, Alatalo P (2004) Distribution of zooplankton on the continental shelf off Marguerite Bay, Antarctic Peninsula, during austral fall and winter, 2001. Deep Sea Research Part II: Topical Studies in Oceanography 51:2073–2098.

Ashton GV, Morley SA, Barnes DK, Clark MS, Peck LS (2017) Warming by 1 C drives species and assemblage level responses in Antarctica's marine shallows. Current Biology 27:2698–2705.

Atkinson A, Hill SL, Pakhomov EA, Siegel V, Reiss CS, Loeb VJ, Steinberg DK, Schmidt K, Tarling GA, Gerrish L (2019) Krill (Euphausia superba) distribution contracts southward during rapid regional warming. Nature Climate Change 9:142.

Atkinson A, Siegel V, Pakhomov E, Rothery P, Loeb V, Ross R, Quetin L, Schmidt K, Fretwell P, Murphy E (2008) Oceanic circumpolar habitats of Antarctic krill. Marine Ecology Progress Series 362:1–23.

Barker P, Thomas E (2004) Origin, signature and palaeoclimatic influence of the Antarctic Circumpolar Current. Earth-Science Reviews 66:143–162.

Barnes DK (2017) Iceberg killing fields limit huge potential for benthic blue carbon in Antarctic shallows. Global Change Biology 23:2649–2659.

Barnes DK (1995) Seasonal and annual growth in erect species of Antarctic bryozoans. Journal of Experimental Marine Biology and Ecology 188:181–198.

Barnes DK, Clarke A (2011) Antarctic marine biology. Current Biology 21:R451–R457.

Barnes DK, Clarke A (1995) Seasonality of feeding activity in Antarctic suspension feeders. Polar Biology 15:335–340.

Barrera-Oro E (2002) The role of fish in the Antarctic marine food web: differences between inshore and offshore waters in the southern Scotia Arc and west Antarctic Peninsula. Antarctic Science 14:293–309.

Birkenmajer K (1994) Evolution of the Pacific margin of the northern Antarctic Peninsula: an overview. Geologische Rundschau 83:309–321.

Borowicz A, McDowall P, Youngflesh C, Sayre-McCord T, Clucas G, Herman R, Forrest S, Rider M, Schwaller M, Hart T, Jenouvrier S, Polito MJ, Singh H, Lynch HJ (2018) Multi-modal survey of Adélie penguin mega-colonies reveals the Danger Islands as a seabird hotspot. Scientific Reports 8:3926.

Branch TA and Butterworth DS (2001). Estimates of abundance south of 60°S for cetacean species sighted frequently on the 1978/79 to 1997/98 IWC/IDCR-SOWER sighting surveys. Journal of Cetacean Research and Management 3, 251–270.

Branch TA, Matsuoka K, Miyashita T (2004) Evidence for increases in Antarctic Blue whales based on Bayesian modelling. Marine Mammal Science 20:726–754.

Cárdenas CA, González-Aravena M, Santibañez PA (2018) The importance of local settings: within-year variability in seawater temperature at South Bay, Western Antarctic Peninsula. PeerJ 6:e4289.

Cárdenas CA, Montiel A (2017) Coexistence in Cold Waters: Animal Forests in Seaweed-Dominated Habitats in Southern High-Latitudes. Marine Animal Forests: The Ecology of Benthic Biodiversity Hotspots:257–276.

Cárdenas CA, Newcombe EM, Hajdu E, Gonzalez-Aravena M, Geange SW, Bell JJ (2016) Sponge richness on algae-dominated rocky reefs in the Western Antarctic Peninsula and the Magellan Strait. Polar Research 35:30532.

CCAMLR (2018) Report on the thirty-seven meeting of the scientific committee.

Chown SL, Lee JE, Hughes KA, Barnes J, Barrett P, Bergstrom DM, Convey P, Cowan DA, Crosbie K, Dyer G (2012) Challenges to the future conservation of the Antarctic. Science 337:158–159.

Cimino MA, Lynch HJ, Saba VS, Oliver MJ (2016) Projected asymmetric response of Adélie penguins to Antarctic climate change. Scientific Reports 6:28785.

Clarke A, Barnes DK, Hodgson DA (2005) How isolated is Antarctica? Trends in Ecology & Evolution 20:1–3.

Clarke A, Johnston NM (2003) Antarctic marine benthic diversity. In: *Oceanography and Marine Biology, An Annual Review, Volume 41*. CRC Press, p 55–57

Cook A, Vaughan D, Luckman A, Murray T (2014) A new Antarctic Peninsula glacier basin inventory and observed area changes since the 1940s. Antarctic Science 26:614–624.

Costa DP, Crocker DE (1996) Marine mammals of the Southern Ocean. In: *Antarctic Research Series*. Hofmann EE, Ross RM, Quetin LB (eds) American Geophysical Union, Washington, D. C., p 287–301.

De Broyer C, Koubbi P, Griffiths H, Grant SA (2014) Biogeographic atlas of the Southern Ocean. Scientific Committee on Antarctic Research Cambridge.

Deppeler SL, Davidson AT (2017) Southern Ocean phytoplankton in a changing climate. Frontiers in Marine Science 4:40.

Ducklow HW (2008) Long-term studies of the marine ecosystem along the west Antarctic Peninsula. 2008-06-27, https://doi.org/10.1016/j.dsr2.2008.05.014, https://hdl.handle.net/1912/2566

Eastman J, Grande L (1989) Evolution of the Antarctic fish fauna with emphasis on the recent notothenioids. Geological Society, London, Special Publications 47:241–252.

Eastman JT (2013) Antarctic fish biology: evolution in a unique environment. Academic Press.

Eastman JT (2017) Bathymetric distributions of notothenioid fishes. Polar Biology 40:2077–2095.

Everson I (2000) Role of krill in marine food webs. 7.3. The Southern Ocean. Krill: biology, ecology and fisheries:194–201.

Flores H, Atkinson A, Kawaguchi S, Krafft BA, Milinevsky G, Nicol S, Reiss C, Tarling GA, Werner R, Rebolledo EB (2012) Impact of climate change on Antarctic krill. Marine Ecology Progress Series 458:1–19.

Forcada J (2008) The impact of climate change on Antarctic megafauna. In: Impacts of Global Warming on Polar Ecosystems (Duarte CM, editor). Fundacion BBVA, p 85–112.

Forcada J, Trathan PN (2009) Penguin responses to climate change in the Southern Ocean. Global Change Biology 15:1618–1630.

Fraser CI, Morrison AK, Hogg AM, Macaya EC, van Sebille E, Ryan PG, Padovan A, Jack C, Valdivia N, Waters JM (2018) Antarctica's ecological isolation will be broken by storm-driven dispersal and warming. Nature Climate Change 8:704.

Fretwell PT, Trathan PN, Wienecke B, Kooyman GL (2014) Emperor penguins breeding on iceshelves. PLoS ONE 9:e85285.

Fuentes V, Alurralde G, Meyer B, Aguirre GE, Canepa A, Wölfl A-C, Hass HC, Williams GN, Schloss IR (2016) Glacial melting: an overlooked threat to Antarctic krill. Scientific Reports 6:27234.

Galindo-Zaldivar J, Gamboa L, Maldonado A, Nakao S, Bochu Y (2004) Tectonic development of the Bransfield Basin and its prolongation to the South Scotia Ridge, northern Antarctic Peninsula. Marine Geology 206:267–282.

Gascón V, Werner R (2009) Preserving the Antarctic marine food web: achievements and challenges in Antarctic krill fisheries management. Ocean Yearbook Online 23:279–307.

Gili J-M, Rossi S, Pagès F, Orejas C, Teixidó N, López-González PJ, Arntz WE (2006) A new trophic link between the pelagic and benthic systems on the Antarctic shelf. Marine Ecology Progress Series 322:43–49.

Gon O, Heemstra PC (1990) Fishes of the Southern Ocean. JLB Smith Institute of Ichthyology Grahamstown.

Griffiths HJ (2010) Antarctic marine biodiversity–what do we know about the distribution of life in the Southern Ocean? PloS ONE 5:e11683.

Griffiths HJ, Meijers AJ, Bracegirdle TJ (2017) More losers than winners in a century of future Southern Ocean seafloor warming. Nature Climate Change 7:749.

Gryz P, Gerlée A, Korczak-Abshire M (2018) New breeding site and records of king penguins (Aptenodytes patagonicus) on King George Island (South Shetlands, Western Antarctic). Polar Record 54:275–283.

Gutt J, Cummings V, Dayton P, Isla E, Jentsch A, Schiaparelli S (2015) Antarctic Marine animal forests: three-dimensional communities in Southern Ocean ecosystems. Marine Animal Forests: The Ecology of Benthic Biodiversity Hotspots:1–30.

Gutt J, Starmans A (2002) Quantification of iceberg impact and benthic recolonisation patterns in the Weddell Sea (Antarctica). In: *Ecological Studies in the Antarctic Sea Ice Zone*. Springer, p 210–214

Harris CM, Lorenz K, Fishpool LDC, Lascelles B, Coope, J, Cori, NR, Croxall JP, Emmerson LM, Fijn RC, Fraser WL, Jouventin P, LaRue MA, Le Maho Y, Lynch HJ, Naveen R, Patterson-Fraser DL, Peter H.-U, Poncet,S, Phillip RA, Southwell CJ, van Franeker JA, Weimerskirch H, Wienecke B, & Woehler EJ. 2015. Important Bird Areas in Antarctica 2015. BirdLife International and Environmental Research & Assessment Ltd., Cambridge.

Herr H, Viquerat S, Siegel V, Kock K-H, Dorschel B, Huneke WG, Bracher A, Schröder M, Gutt J (2016) Horizontal niche partitioning of humpback and fin whales around the West Antarctic Peninsula: evidence from a concurrent whale and krill survey. Polar Biology 39:799–818.

Hinke JT, Cossio AM, Goebel ME, Reiss CS, Trivelpiece WZ, Watters GM (2017) Identifying risk: concurrent overlap of the Antarctic krill fishery with krill-dependent predators in the Scotia Sea. PLoS ONE 12:e0170132.

Hopkins T (1985) Food web of an Antarctic midwater ecosystem. Marine Biology 89:197–212.

Hughes KA, Ireland LC, Convey P, Fleming AH (2016) Assessing the effectiveness of specially protected areas for conservation of Antarctica's botanical diversity. Conservation Biology 30:113–120.

Ingels J, Vanreusel A, Brandt A, Catarino AI, David B, De Ridder C, Dubois P, Gooday AJ, Martin P, Pasotti F (2012) Possible effects of global environmental changes on Antarctic benthos: a synthesis across five major taxa. Ecology and Evolution 2:453–485.

Juáres MA, Ferrer F, Coria NR, Santos MM (2017) Breeding events of king penguin at the South Shetland Islands: Has it come to stay? Polar Biology 40:457–461.

Kasamatsu F and Joyce GG (1995). Current status of odontocetes in the Antarctic. Antarctic Science 7, 365–379.

Kavanagh A, Bransome N, Werner R (2017) Towards Creation of a CCAMLR Network of Marine Protected Areas in the Southern Ocean.

Kawaguchi S, Ishida A, King R, Raymond B, Waller N, Constable A, Nicol S, Wakita M, Ishimatsu A (2013) Risk maps for Antarctic krill under projected Southern Ocean acidification. Nature Climate Change 3:843.

Klöser H, Quartino ML, Wiencke C (1996) Distribution of macroalgae and macroalgal communities in gradients of physical conditions in Potter Cove, King George Island, Antarctica. Hydrobiologia 333:1–17.

Lagger C, Nime M, Torre L, Servetto N, Tatián M, Sahade R (2018) Climate change, glacier retreat and a new ice-free island offer new insights on Antarctic benthic responses. Ecography 41:579–591.

Lagger C, Servetto N, Torre L, Sahade R (2017) Benthic colonization in newly ice-free soft-bottom areas in an Antarctic fjord. PloS ONE 12:e0186756.

Lagos PF, Manríquez K (2014) Spatial distribution of Antarctic copepods in Fíldes Bay during summer of 2012. Revista de biología marina y oceanografía 49:537–546.

Landaeta MF, López G, Suárez-Donoso N, Bustos CA, Balbontín F (2012) Larval fish distribution, growth and feeding in Patagonian fjords: potential effects of freshwater discharge. Environmental Biology of Fishes 93:73–87.

Lawver LA, Gahagan LM (1998) Opening of Drake Passage and its impact on Cenozoic ocean circulation. Oxford Monographs on Geology and Geophysics 39:212–226.

Le Quéré C, Rödenbeck C, Buitenhuis ET, Conway TJ, Langenfelds R, Gomez A, Labuschagne C, Ramonet M, Nakazawa T, Metzl N (2007) Saturation of the Southern Ocean CO2 sink due to recent climate change. Science 316:1735–1738.

Lee JR, Raymond B, Bracegirdle TJ, Chades I, Fuller RA, Shaw JD, Terauds A (2017) Climate change drives expansion of Antarctic ice-free habitat. Nature 547:49.

Lockyer C, Brown S (1981) The migration of whales. In: *Animal migration*. Cambridge University Press New York, NY, p 105–137.

Lowther AD (2018) Antarctic Marine Mammals. In: *Encyclopedia of Marine Mammals*. Elsevier, p 27–32.

Lynch HJ, Naveen R, Trathan PN, Fagan WF (2012) Spatially integrated assessment reveals widespread changes in penguin populations on the Antarctic Peninsula. Ecology 93:1367–1377.

Lynnes A (2019) The International Association of Antarctica Tour Operators: 28 Years and Counting.

Mathiot P, Jenkins A, Harris C, Madec G (2017) Explicit representation and parametrised impacts of under ice shelf seas in the z∗ coordinate ocean model NEMO 3.6, Geosci. Model Dev., 10, 2849–2874.

Meredith MP, King JC (2005) Rapid climate change in the ocean west of the Antarctic Peninsula during the second half of the 20th century. Geophysical Research Letters 32.

Moffat C, Meredith M (2018) Shelf–ocean exchange and hydrography west of the Antarctic Peninsula: a review. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 376:20170164.

Moore JK, Abbott MR, Richman JG (1997) Variability in the location of the Antarctic Polar Front (90–20 W) from satellite sea surface temperature data. Journal of Geophysical Research: Oceans 102:27825–27833.

Orsi AH, Whitworth III T, Nowlin Jr WD (1995) On the meridional extent and fronts of the Antarctic Circumpolar Current. Deep Sea Research Part I: Oceanographic Research Papers 42:641–673.

Peck LS, Morley SA, Clark MS (2010) Poor acclimation capacities in Antarctic marine ectotherms. Marine Biology 157:2051–2059.

Peck LS, Webb KE, Bailey DM (2004) Extreme sensitivity of biological function to temperature in Antarctic marine species. Functional Ecology 18:625–630.

Pitman RL, Ensor P (2003) Three forms of killer whales (Orcinus orca) in Antarctic waters. Journal of Cetacean Research and Management 5:131–140.

Rovelli L, Attard KM, Cárdenas CA, Glud RN (2019) Benthic primary production and respiration of shallow rocky habitats: a case study from South Bay (Doumer Island, Western Antarctic Peninsula). Polar Biology:1–15.

Rückamp M, Braun M, Suckro S, Blindow N (2011) Observed glacial changes on the King George Island ice cap, Antarctica, in the last decade. Global and Planetary Change 79:99–109.

Sahade R, Lagger C, Torre L, Momo F, Monien P, Schloss I, Barnes DK, Servetto N, Tarantelli S, Tatián M (2015) Climate change and glacier retreat drive shifts in an Antarctic benthic ecosystem. Science Advances 1:e1500050.

Santos MM, Hinke JT, Coria NR, Fusaro B, Silvestro A, Juáres MA (2018) Abundance estimation of Adélie penguins at the Esperanza/Hope Bay mega colony. Polar Biology 41:2337–2342.

Smale DA, Brown KM, Barnes DK, Fraser KP, Clarke A (2008) Ice scour disturbance in Antarctic waters. Science 321:371–371.

Smith KE, Aronson RB, Thatje S, Lovrich GA, Amsler MO, Steffel BV, McClintock JB (2017) Biology of the king crab Paralomis birsteini on the continental slope off the western Antarctic Peninsula. Polar Biology 40:2313–2322.

Thatje S (2005) The future fate of the Antarctic marine biota? Trends in Ecology & Evolution 20:418–419.

Thatje S, Hall S, Hauton C, Held C, Tyler P (2008) Encounter of lithodid crab Paralomis birsteini on the continental slope off Antarctica, sampled by ROV. Polar Biology 31:1143–1148.

Thomas ER, Bracegirdle TJ, Turner J, Wolff EW (2013) A 308 year record of climate variability in West Antarctica. Geophysical Research Letters 40:5492–5496.

Torre L, Servetto N, Eöry ML, Momo F, Tatián M, Abele D, Sahade R (2012) Respiratory responses of three Antarctic ascidians and a sea pen to increased sediment concentrations. Polar Biology 35:1743–1748.

Trathan PN, Warwick-Evans V, Hinke JT, Young EF, Murphy EJ, Carneiro APB, Dias MP, Kovacs KM, Lowther A, Godø OR (2018) Managing fishery development in sensitive ecosystems: identifying penguin habitat use to direct management in Antarctica. Ecosphere 9:e02392.

Trivelpiece WZ, Hinke JT, Miller AK, Reiss CS, Trivelpiece SG, Watters GM (2011) Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. Proceedings of the National Academy of Sciences 108:7625–7628.

Turchik, A. J., Berkenpas, E. J., Henning, B. S., & Shepard, C. M. (2015). The Deep Ocean Dropcam: a highly deployable benthic survey tool. In OCEANS'15 MTS/IEEE Washington (pp. 1–8). IEEE.

Turner J, Overland J (2009) Contrasting climate change in the two polar regions. Polar Research 28:146–164.

Vaughan DG, Corr HF, Ferraccioli F, Frearson N, O'Hare A, Mach D, Holt JW, Blankenship DD, Morse DL, Young DA (2006) New boundary conditions for the West Antarctic ice sheet: Subglacial topography beneath Pine Island Glacier. Geophysical Research Letters 33. L09501, doi:10.1029/2005GL025588.

Visser IN, Smith TG, Bullock ID, Green GD, Carlsson OG, Imberti S (2008) Antarctic peninsula killer whales (Orcinus orca) hunt seals and a penguin on floating ice. Marine Mammal Science 24:225–234.

Waring G, Josephson E, and Fairfield-Walsh C. (2007). US Atlantic and Gulf of Mexico marine mammal stock assessments. NOAA Tech. Memo. NMFS NE, 205, 415 pp.

Weinstein BG, Double M, Gales N, Johnston DW, Friedlaender AS (2017) Identifying overlap between humpback whale foraging grounds and the Antarctic krill fishery. Biological Conservation 210:184–191.

Werner R, Bransome N (2017) Progress Toward the Establishment of Marine Protected Areas in the Rapidly Changing Western Antarctic Peninsula. AGENDA ANTÁRTICA:31.

NATIONAL GEOGRAPHIC
PRISTINE SEAS

Instituto Antártico Chileno
Ministerio de Relaciones Exteriores
Gobierno de Chile

Chile en marcha

Dirección Nacional del Antártico
Instituto Antártico Argentino

Ministerio de Relaciones Exteriores y Culto
República Argentina

Antarctic and Southern Ocean Coalition